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A REVIEW OF REPRESENTATIVE TESTS USED FOR THE QUANTITATIVE MEASUREMENTS OF BEHAVIOR-DECREMENT UNDER CONDITIONS RELATED TO AIRCRAFT FLIGHT

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UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
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ABSTRACT

This report summarizes and attempts to correlate and evaluate quantitative tests, reported in English since about 1920, used to measure behavior-decrement under the following principal conditions: altitude, vibration, noise, temperature, humidity, 'fatigue', apprehension, stress, and others. The bibliography exceeds 500 references. In Section I tests are described, skeleton data tabulated, and analysis-variables discussed. Results obtained under altitude, noise, vibration, and temperature are summarized. There is apparently no single index of general 'psychomotor performance'. Section II reviews studies on 'fatigue', loss of sleep, apprehension and stress, with concluding emphasis upon configuration of the complex reaction pattern and motivation. Promising scoring indices are (1) ratio of errors and duration to number of movements; (2) instances of omissions of parts of complex tasks, reflecting 'lowered standard'; (3) variability of response; (4) occurrence of 'blocking'; disruptions in (5) timing, and (6) the configurational pattern. Additional test-categories, considered beyond the scope of the report, are included in the Appendix.

FOREWORD

This report was prepared by Oberlin College, Oberlin, Ohio, under USAF Contract No. W33-038 ac-19047 (18876). The contract was initiated by Dr. J. W. Heim, MCREXDS, under the research and development project, initiated by Expenditure Order No. 696-61, and it was administered under the direction of the Aero Medical Laboratory, Headquarters, Air Materiel Command, with Dr. Louis D. Hartson and Dr. John L. Finan as supervisors. The accumulation of bibliography and compilation of Section I is chiefly the work of Mrs. Sarah C. Finan, the writing of the Introduction and Section I, including the evaluation of performance tests, of Dr. Finan. Dr. Hartson has been largely responsible for Section II.

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A REVIEW OF REPRESENTATIVE TESTS USED FOR THE QUANTITATIVE MEASUREMENTS OF BEHAVIOR-DECREMENT UNDER CONDITIONS RELATED TO AIRCRAFT FLIGHT.

INTRODUCTION

Nature and Purpose of the Report

This report attempts to summarize, correlate and evaluate quantitative tests which have been used to measure psychological performance under a variety of conditions similar to those encountered in flying. Tests included are those which are representative of efforts to quantify performance under the following conditions: altitude, vibration, noise, temperature, humidity, fatigue, apprehension, stress, drugs, dietary factors and others.

Scope of the Study

The extremely large volume of literature found in this field necessitated a delimitation of the materials to be included.

No attempt has been made to include tests designed primarily for selection and classification of individuals. Testing instruments devised primarily for this purpose, while by no means without bearing on the problem of performance, are usually constructed on different principles. For the task in hand it has been assumed that the performance test differs at least in emphasis from the predictive index in that its primary goal is the isolation of basic functions of behavior. Partly for this reason the performance test does not, as a rule, have its rationale in a job analysis of some complex task, and is not likely to be systematically interpretable if it is no more than a 'miniature situation' or 'work-sample' whose justification is that it correlates with a prescribed 'criterion'. Instead, the validity of a test of performance is established by demonstrating its covariation with the environmental condition under investigation. Even though the same test is occasionally used for both purposes, important differences between the two kinds of instruments are obscured unless this distinction is borne in mind.

Tests which were regarded as primarily physiological[1] were excluded from the report. Here again the distinction is not an absolute one, since the areas of psychology and physiology are overlapping to a considerable degree. When a physiological process is of interest mainly as an index of impairment[2] of more

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[1] See table A-5 and A-7 in appendix.

[2] See tables A-2 and A-6 in appendix.

complex behavior functions, it has been regarded as of secondary importance and included in the appendix. Critical Flicker Frequency is an example in point since workers in this field of research have exploited it, in the main, not merely as a test of visual function, but as a quantitative measure of 'fatigue'. Simple sensory functions represent another category of behavior excluded from detailed consideration. A sample of sensory tests[1] has been appended largely on the ground that psychologists are sometimes forced to consider sensory acuity in order to eliminate impairment in this factor, which is a necessary condition of almost all behavior.

At the other extreme of behavioral complexity, intelligence and personality tests have been included only to a minimum extent.[2] This exclusion is based in part on their concern with problems of predicting individual differences. Where, however, types of items have been broken out of intelligence tests for separate study as possible unitary factors, they have, in representative cases, been included in the report.

Clinical tests, while they yield many leads as to behavioral processes affected by impairment of the nervous system, or of other integrative mechanisms of the organism, have been omitted as a group because of their non-quantitative character. Tests of 'abstraction', 'categorization' and similar tests primarily validated against clinical evidence, might profitably be made the subject of a separate report.

The literature emerging from World War I has been covered only sporadically on the ground that 'promising' tests developed during this early period have since been exploited and results incorporated into the more recent literature.

Within the field as thus restricted, the literature in English[3] has been systematically covered through December, 1948. The range of information embraced will be seen to be extremely broad, but perhaps no more so than a preliminary attack on this field justifies.

Technique of the Study

Abstracts from the relevant articles included data on the nature of subjects, conditions, tests employed and methods of analysis, together with special features of a particular study.

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[1] See tables A-1, A-3 and A-4 in appendix.

[2] See tables A-8 and A-9 in appendix.

[3] A few studies in French and German are included. References searched in foreign languages yielded only a small number of articles, which were, for the most part, non-quantitative.

Articles were searched for information according to a set of general categories adopted as a result of reading a preliminary sample of materials to be covered:

1. Subject-variables included, in addition to number of individuals studied, such background factors as age, sex, educational status, occupational status, previous experience related to test, and the like. Whenever the information was available, note was made of the manner in which the population studied was selected, and of possible controls exercised on the subjects' living regime during the course of an extended experiment.

2. Condition-variables included not merely a statement of the gross stimulating circumstance, but how it was obtained, in what degree it was present, its duration, and the like. In studies of altitude, for example, it is important to know, in addition to height or partial pressure of oxygen, duration of ascent, length of stay at altitude, and method of producing the condition, whether by means of a decompression chamber, a rebreathing apparatus or actual climbing or flying. Similarly, in alcohol studies, as noted by Jellinek and McFarland (1940) account must be taken of such factors as "modus of alcohol administration (standard dosages, dosages per kilogram of body weight, oral or intravenous administration, amount, dilution, disguise of drink, rate of drinking, etc.), the time of alcohol administration in relation to food intake, rest... the time between alcohol ingestion and test observation....and many other factors". Other conditions such as temperature, noise, vibration, required that corresponding information be noted, when available.

3. Test-variables were of primary significance and embraced such factors as the design of the experiment, additional tests, if the particular test was one unit in a battery, its position in the battery, instructions given to the subject, apparatus employed, characteristics of response, and methods of recording. In addition, practice effects, length of test, motivation of subject, and the like, were noted.

4. Analysis-variables included among other things the index of scoring, the validity, sensitivity and reliability of the test. The index of scoring selected for measurement may often differ within a single test. In tests of complex-reaction time, for example, it is likely to be crucial whether a decrement is expressed in terms of time or errors. Validity in performance tests, as noted above, refers to the correlation between behavior and the experimental condition. A test for the effects of altitude is thus valid if it can be demonstrated that the single variable or isolated complex of variables which is identifiable yields a given degree of performance at one height, and another, at a different height. The greater the range of the condition over which such correspondence obtains, other factors equal, the greater the sensitivity of the test. An adequate evaluation of reliability

rests on a number of factors in addition to a correlational value expressing the consistency of the test as a measure of performance. Information should be gathered concerning the probable error of the correlation, its derivation from intra-test or inter-test data, number of subjects on which a reliability coefficient is based, trial sequences correlated, number of trials employed in the calculation, and other factors. Since relative susceptibility or insusceptibility of a test to practice bears importantly on its reliability, this feature should be noted. Whether the reliabilities were actually estimated under a particular condition, or independently, was regarded as important. Finally, interpretation of the data was given special attention either with respect to the investigator's hunch as to the function being measured when offered, or, more importantly, with respect to intercorrelations with other tests.

In practice, few articles were found in which all the information demanded by these desiderata was given. Comparison between tests is probably unjustified without equation of all of these factors, yet there appears to be some point to making a preliminary assessment of the accumulated evidence, on a broad basis. On this assumption, tests and conditions were therefore grouped together and compared, in most cases, without complete regard for these requirements. Both the mass of evidence and the inadequacy of experimental accounts frequently preclude the possibility of rendering experimental data into common terms. Results have therefore usually been reported as positive or negative, depending on the stated conclusions of the experimenter. Refinement of analysis beyond this point, while highly desirable, would be incompatible with an effort as comprehensive as the present review. It is significant that consistency of results, both of tests and conditions, appears despite the inadequate founding of many of the studies. The discussion which follows is largely based on a series of tables summarizing results by type of test, and later by conditions. The classification of the data required by tabular presentation should not be construed as having any purpose beyond that of an expository device. An attempt has been made to include within the tables features of the data which are important to their evaluation.

SECTION I

DESCRIPTION AND TABULATION OF PERFORMANCE TESTS

Plan of discussion

The plan of discussion for each group of test results usually includes a brief consideration of some of the major factors requiring control. Next, brief descriptions of the essential features of the procedure, the apparatus, task required of subject, and the like, are given for those tests which are deemed most representative of the group. Following this, findings obtained under the several conditions are considered. The distribution characteristics for one or more representative tests are next given. Finally, intercorrelational, factor analytic, and other interpretive data are

brought to bear on the problem of interpreting the nature of the psychological functions measured by the test.

The Problem of Classifying the Tests

The status of information in the field of performance testing does not, at present, suggest a consistent classification in terms of basic psychological components. More or less arbitrary classifications have been employed in the past by Whipple (1914), Muscio (1922), Garrett and Schneck (1933), and more recently by Melton (1947) and by Guilford (1947). In the discussion to follow, a number of possible organizing principles have been relied on, but without any attempt at a rigorously systematic classification of tests. Classified according to the kind of stimulus presentation, tests range from those demanding simple sensory functions, to those which depend on more complex principles or symbolic factors. In the latter, 'interpretability' of the presentation is stressed, with a minimization of 'acuity' and 'discrimination' factors which are emphasized in the former. Classified in terms of response, tests vary from those which stress relatively simple motor functions, to others in which the reaction is of a highly complex verbal or 'ideational' type. Further significant distinctions in response based on types of movement, bodily members involved, discrete or non-discrete character, will be developed as needed in the ensuing discussion. Non-discrete movements are divided into those which are repetitive, serial and continuous (Fitts 1947) when appropriate to differentiation of the tests.

Learning, which provides a further basis of test classification, may, for purposes of this report, be regarded as a long-sectional dimension of behavior that has relevance for any performance in so far as it may be modified by practice. Motivation is similarly a category applicable to performance in general. It is apparent that any measure of performance makes demands on the sensory, motor and coordinating capacities and reflects the learning and motivation of the individual under test. At most, therefore, any one of these factors may be examined while the remaining ones are minimized or held constant. Tests are usually identified by little more than common features of the test situation, and distinctions observed in the discussion to follow, hew closely to differences in testing operations and procedures. The order of presentation of the tests will be seen to move roughly from the simple to more complex psychological functions, although inversions resulting from the many types of possible variation within the same testing situation, can be observed.

Groups of Tests

1. Tests of Simple Reaction Time

Tests in this group have as a common characteristic the requirement that the subject respond as rapidly as possible to the discrete presentation of a single stimulus. In the typical simple visual reaction time situation the subject responds to the onset of

light by depressing a key. The character of the stimulation is not limited to visual cues, however, and is frequently based on auditory, tactile, or on other sensory fields. Responses chosen for measurement include, in addition to movement of the hand, that of the eye, mouth (word-reaction), foot or toe, or of the body as a whole. Normative data comparing response latencies for several sensory modalities are given by Forbes (1945), and for response-members by Seashore and Seashore (1941). While the movements involved are relatively simple, they differ from test to test and may, for example, involve lifting the finger from a key already depressed, or moving the hand from a designated place on the apparatus to a key. Latency of response is standardly measured with a chronoscopic device. A variety of methods employed in the measurement of simple reaction time are described by Miles (1931).

Consideration of the accompanying Table 1, Part I, which summarizes the influence of the selected environmental conditions on simple reaction-time tests of various kinds, shows that increased reaction latencies have been obtained with extended periods spent at high altitudes (17,000 - 20,000 feet) (McFarland 1932, 1937), although Wespi (1933, 1936) failed to note decrement at approximately 16,500 feet in a U-chamber. Five studies of sleep privation (Patrick and Gilbert 1896; Lee and Kleitman 1923; Cooperman, Mullin and Kleitman 1934; Tyler 1947; Edwards 1941) are consistent in showing no decrement in simple reaction time. A study by Jones et al (1941) demonstrates an increase in response-latency in truck drivers as a function of hours of driving. Alcohol (Varé 1932) and morphine (Macht and Isaacs 1917) depress the function. Vibration yielded no effect (Coerman 1939). Additional results obtained under various conditions may be noted in Table 1.

In Part II of Table 1 are presented results obtained with variant procedures involving responses other than manual. Alcohol (Miles 1924) depresses reactions of the present type as do lack of Vitamin-B during the period of acute deficiency (Brozek et al 1946), and 'flagging of attention' (Travis and Kennedy 1947). With carbon monoxide (Forbes, Dill et al 1937), except in concentrations of 30% or higher, no effects were noted.

Reliability of a simple reaction-time test was computed as .72 by Farnsworth, Seashore and Tinker (1927) in a standardization study. Seashore and Seashore (1941) in an independent study give reliability coefficients of .87 - .90 (uncorrected) for simple hand and foot responses to an auditory stimulus. The generally accepted observation that reaction time is relatively slightly influenced by practice may suggest one factor contributing to its relatively high reliability. Distraction, however, is reported to be capable of producing a marked diminution in reliability of simple reaction-time, at least under some conditions.

Simple reaction time scores have come to be accepted by many workers as measures of habitual tasks. According to Seashore, Buxton and McCollom (1940) a group factor can be analyzed from a variety of reaction time tests. Intercorrelational data shed further light on the nature of the function measured by the present type of test: Forbes (1945) gives the correlation between response to light and sound as .48. Results showing relatively high intercorrelations of various types of simple reaction tests are reported by Farnsworth, Seashore and Tinker (1927). The same investigators report high correlations between right and left hands, as well as between forms of the test in which the subjects are prepared and unprepared. Results agree that simple reaction-time shows no relation to general intelligence (Sisk 1926; Farnsworth, Seashore and Tinker 1927). In the same study Sisk (1926) also shows absence of correlation with such complex tests as substitution or card-sorting. According to data obtained by Seashore, Buxton and McCollom (1940), the auditory reaction has little or no correlation with single- or double-plate tapping; the visual form, however, showed a low degree of relationship with single-plate tapping. Further evidence from the same experiments showed no correlation of simple reaction time with a discrimination reaction time test and with a pursuit rotor test. A part of the importance of tests of this type stems from the widely held, but unsubstantiated, hypothesis that complex tests of a sensorimotor type are built up from simple reaction units.

2. Tapping Tests

Tests falling under the category of tapping appear to differ from those of simple reaction time significantly in the respect that responses must be repeated in immediate succession. As an implication of this difference, it is reasonable to suppose that each successive response in the case of tapping is dependent on stimulus cues produced by the preceding response. Both appear to be primarily tests of speed with minimisation of a precision factor. The variety of methods employed in the literature varies from simple finger oscillation to complex simultaneous movements of the two hands. This diversity of techniques makes it difficult to generalize about tests of tapping. Representative tests will be found in the following sources: one-plate, with stylus technique, Whipple (1914); counter or telegraph-key, Garrett and Schneck (1933); two-plate, with stylus, Dunlap (1921), Garrett and Schneck (1933); two-plate with finger, Finan and Malmo (1944); two telegraph keys, Stevens (1941); two-plate with both hands, Birren and Fisher (1945). Revisions in the design of apparatus and technique for measurement of tapping represent efforts to control such variable factors as 'tremor tapping' (minimized by requiring alternate response on each of two plates), differing leverages on stylus (minimized by responding directly with the finger), and sliding from plate to plate (minimized by separating the plates by means of a rais barrier). In the standard version of the tapping test the subject is

Table 1

SIMPLE REACTION TIME TESTS
(Classified according to type of response)

Code to results:
(-) = decrement (lengthened reaction time); (o) = no change; (+) = increment (shortened reaction time); (?) = inconclusive.

Source	Year	Stimulus	Condition	Subjects	Results Code	Results Remarks
			I. Hand or finger response A. Coordination time (self initiated)			
Miles	1931	(none)	Normal	100 (25-87 yrs.)		Mean = 0.159 sec. Increase with age.
			B. Pressing key or lifting finger from key			
Patrick and Gilbert	1896	Auditory or Visual	Sleep privation (90 hrs.)	3	(o)(?)	
Macht and Isaacs	1917	Tactile, Visual	Morphine alkaloids	12	(+) (-)	Primary effect. Secondary and large dosage.
Henmon	1919	Auditory or Visual	Normal	300 flyers		Low correlation with flying ability.
Lee and Kleitman	1923	Auditory or Visual	Sleep privation (114 hrs.)	1	(o)	
Miles	1931	Auditory or Visual	Normal	100 (25-87 yrs.)		Mean times: 0.227 sec. 0.241 sec.
McFarland	1932	Visual	Anoxia (rebreathing)	9	(-)	At high equivalent altitudes only.

Table 1 (con.)

SIMPLE REACTION TIME TESTS

Source	Year	Stimulus	Condition	Subjects	Results: Code	Results: Remarks
Vare	1932	Auditory and visual	Alcohol		(-)	and greater variability.
Cooperman et al	1934	Auditory	Sleep privation (60 hrs.)	6	(o)	
Wespi Wespi	1935 1936		Altitude (3,500, 5,000 & 7,000 meters)	12	(o)	at 3,500 and 5,000 meters.
Fay	1936	Visual	Smoking	11 smokers 10 non-smokers	(?)	variability
Davis, R. C.	1936	Auditory or visual	Aspirin	33	[illegible]	
McFarland	1937-I	Visual	Altitude-rapid ascents	6	o)	14,890 ft.
	1937-II	Visual	Altitude - acclimatization	10	(o) (-)	No change until 20,140 ft. Increased variability at 17,500 ft.
	1937-IV	Visual	Altitude	35 native miners 35 natives at sea level		Longer and more variable than workmen at sea level.
Kleitman, et al	1938	Auditory	Diurnal variations	5	(+) (-)	Shortest in afternoon.
Gilliland and Nelson	1939	Auditory	Coffee	5	(-)	

Table 1 (con.)

SIMPLE REACTION TIME TESTS

Source	Year	Stimulus	Condition	Subjects	Results Code	Results Remarks
Coerman	1939	Visual	Vibration (15 - 1000 Hertz)	(2 - 12)	(o)	May be impaired at small amplitudes.
Thornton, Holck & Smith	1939	Auditory	Benzedrine	3	(+)(?)	Slight
			Caffeine		(o)	
Edwards	1941	Visual or auditory	Sleep privation (100 hrs.)	19 exper. 10 control	(o)	Tendency for subject to fall asleep during 50 trials.
Jones et al	1941	Visual - auditory	Hours of driving	659 truck drivers	(-)	Significant increase with hours of driving.
Forbes, G.	1945	Visual	Normal	178		
			-practice		(+)	Slight
			hours since rising		(o)	
			age		(o)	
		Auditory	-practice		(o)	
			hours since rising		(o)	
			age		(+)	Increase with age.
Tyler	1947	Visual or auditory	Sleep privation (24-114 hrs.)	(not stated)	(o)	
Tuttle et al	1949	Visual	Diet - omission of breakfast	5	(-)	

Table 1 (con.)

SIMPLE REACTION TIME TESTS

Source	Year	Stimulus	Condition	Subjects	Results: Code	Results: Remarks
Muscio	1922	Auditory	Normal	88		All give data on reliabilities (r = high = .83 to .92). All types of simple reactions correlate highly with each other. Do not correlate with intelligence or other motor skills.
Farmer and Chambers	1926	Visual	Normal	(various)		
Sisk	1926	Tactile, visual	Normal	100		
Farnsworth et al	1927	Auditory, visual	Normal	50		
Seashore, Buxton et al	1940	Auditory, visual	Normal	50		
Seashore, Starman et al	1941	Auditory, visual	Normal	47		
Gray and Trowbridge	1942	Auditory, visual	Normal	0		
Slocombe and Brakeman	1930	Visual	% accident rate	86 motormen		Reaction time test scores yield a factor "g" differentiating poor accident risks.
			II. Other responses. **A. Foot or toe reaction**			
Miles	1931	Auditory	Normal	100 (25-87 yrs.)		Mean time = 0.242 sec.
Brozek et al	1946	Auditory	Diet-Vit.B deficient-161 days partial, 23 days acute	8	(o) (-)	No change in partial restriction during acute period, signif. at 5% level (t = 2.57)

Table 1 (con.)

SIMPLE REACTION TIME TESTS

Source	Year	Stimulus	Condition	Subjects	Results: Code	Results: Remarks
Forbes, Dill et al	1937	Visual-red light	Carbon monoxide	8	(o)	No change until saturation 30% or more.
			B. Various (Foot, hand, jaw)			
Seashore and Seashore	1941	Auditory	Normal	50		Intercorrelations between response units high.
			C. Hand response to stimulus set off by lowered muscle tension.			
Travis and Kennedy	1947	Visual	Lack of alertness		(-)	Longer reaction times with lowered tension.
Kennedy and Travis	1947	Visual	Lack of alertness			
			D. Reaction time to vestibular stimuli			
Baxter and Travis	1938	Tilting	Normal	32		Average reaction time = 0.598 sec.
			E. Eye reaction			
Miles	1924	Visual-light	Alcohol	8	(-)	
			F. Vocal response			
Macht and Isaacs	1917	Auditory	Morphine and related alkaloids	12	(+) (-)	Primary effect of small doses. Secondary effect of small doses and large doses
Miles	1924	Visual-words	Alcohol		(-)	
Hull	1924	Visual-words	Smoking	Smokers Non-smokers		Variable

required to respond with a stylus held in the preferred hand by alternately tapping on two plates separated by a short distance. Number of taps per unit time is recorded on an automatic counter which is actuated by contact of the stylus with the plates.

Results obtained with various types of tapping tests are arrayed in Table 2. Under actual or simulated altitude, deficit is reported by three investigators (Bagby 1921; Lowson 1923; Malmo and Finan 1944), but only in advanced stages or under rather extreme conditions. Seven studies of sleep privation agree in reporting absence of effects on tapping performance (Patrick and Gilbert 1896; Robinson and Herrmann 1922; Husband 1935; Katz and Landis 1935; Warren and Clark 1937; Edwards 1941; Tyler 1947). Alcohol is reported to have a depressing effect on speed of tapping (Hollingworth 1923-24; Miles 1924), while benzedrine has been found to facilitate it slightly, by several investigators (Carl and Turner 1939 and 1940; Thornton, Holck and Smith 1939; Simonson and Enzer 1941). Flory and Gilbert (1943), while obtaining findings with benzedrine similar to those reported above, point to suggestion as a possible factor in the determination of the result. Results with caffeine parallel those considered immediately above, showing a slight stimulating effect on the present type of performance (Hollingworth 1912; Flory and Gilbert 1943). Other data summarized in Table 2 indicate performance deficits under dietary deficiencies (Taylor et al 1945; Glickman et al 1946) and cold (Keeton et al 1946; Mitchell et al 1946), and absence of clear cut impairment with smoking (Hull 1924), carbon monoxide (Dorcus and Weigand 1929), adrenaline (Jersild and Thomas 1931) and noise (Stevens 1941).

Reliability coefficients are given by Muscio (1922-23) for the one-plate form as .86 (trials 1 - 4) and .92 (trials 21-24). Malmo and Finan (1944), using a two-plate, non-stylus apparatus, calculate an intratest coefficient of .94 (corrected .97) under test-retest conditions, however the reliability depreciated to .37, for trials 1 and 2, rising to .76 for trials 2 and 3. Melton (1947) has recently reported for a two-plate stylus technique, an intratest value of .96, based on the first three minutes of tapping, and a coefficient of .94, based on the last three minutes of an eight minute period. According to Muscio (1922-23) the reliability of the test increases once the limit of improvement is reached. In general, investigators are agreed that during a brief initial period the tapping test is highly susceptible to practice.

Intercorrelations between single performances on two- and three-plate tests have been demonstrated by Seashore, Buxton and McCollom (1940) to yield an interpretable pattern, with the least inter-relationship between the one- and the three-plate techniques. In the same study vertical telegraph key tapping correlated considerably higher with horizontal telegraph key tapping than with the one-plate tapping, diminishing with the two- and still further with the three-plate apparatus. Moderate correlation values are reported by

Melton (1947) between tapping and discrimination reaction, two hand coordination, and the SAM complex coordinator. As noted previously, it has been shown by numerous experiments that little relationship obtains between tapping and simple reaction time. A low correlation has been found between tapping and body sway (Seashore, Buxton and McCollom 1940). A factor analytic study by Melton (1947) indicates that tapping performance has a unique loading interpreted as a 'wrist' factor. Seashore (1940) reports two factors involved in tapping: one for movement within a single plane measured by the telegraph key or one-plate apparatus, another sampled by the multiple-plate technique in which at least a minimum of precision is a requirement. A further finding of little or no communality between tapping and tremor suggests that the two types of response may be differentiated as voluntary and involuntary.

3. Tests of Static Steadiness

On the level of testing operations, steadiness differs from the sensori-motor tests considered up to this point significantly in its emphasis on precision rather than speed. Tests of the present type are considered to measure control of fixed movement, or amount of uncontrolled movement which occurs when the hand, arm, finger, head, or other reaction systems, including the entire body, are held as nearly motionless as possible in a specified position for a fixed time.

Arm-hand steadiness is the most frequently used form of steadiness test. In the representative manual steadiness test a needle-stylus of constant diameter is inserted and held for a fixed time in each of a series of calibrated holes of varying size, drilled in a sloping panel. The stylus must be held toward the center of the hole in order to avoid actuating a counter which automatically records number or duration of contacts. Descriptions of commonly used versions of this test are to be found in Whipple (1914), Dunlap (1921), Garrett and Schneck (1933), Jones et al (1941), Finan and Malmo (1944), and Melton (1947). Factors which vary from test to test are: (1) diameter and effective length of stylus; diameter and number of holes; (2) index of scoring, whether in terms of time or number of contacts; (3) distance of panel from subject; (4) illumination of holes; (5) angle at which stylus is inserted; (6) progress of the trials from small to large, or large to small, or randomized, with multihole tests; (7) subject's knowledge of results; (8) duration of trial period; (9) number of trials; (10) periodicity of trials; and (11) duration of intertrial periods.

Diverse tests of stationary steadiness appear from Table 3 to show uniformly some degree of decrement under many of the conditions examined. With simulated altitude, five studies show a decrement beginning at 12,000 feet, becoming progressively more pronounced with

Table 2

TAPPING TESTS
(Classified according to apparatus used)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Finger movements			
Miles	1924	Alcohol	8	(-)	
		B. Telegraph key			
Hull	1924	Smoking	19	(+) (-)	Slight for non-smokers. Slight for smokers. Considerable variability.
		C. Impulse counter lever or button			
Lowson	1923	Altitude	5	(o)	Until 50% decrease in O_2.
Gilliland and Nelson	1939	Coffee	5	(-)	5 to 10%.
Simonson and Enzer	1941	Benzedrine	4	(+)	
Flory and Gilbert	1943	Benzedrine Caffeine Suggestion	129	(+)(?) (+)(?) (+)(?)	Increased variability. Results are both (+) and (?) for drugs.
		D. One-plate, stylus			
Patrick and Gilbert	1896	Sleep privation (90 hrs.)	3	(o)	
Hollingworth	1912	Caffeine	16	(+)	4%
Hollingworth	1914	Diurnal change	15	(+) (-)	Some evidence of diurnal change.

Table 2 (con.)

TAPPING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Smith, M.	1916	Fatigue	(few)	(o)	Not useful for fatigue test.
Robinson and Herrmann	1922	Sleep privation (60-65 hrs.)	3	(o)	
Muscio	1922-23	Fatigue	(groups of workers)	(o)	Reliability of test increases with practice.
Johnson, B. J.	1922	Fatigue	(children)	(o)(?)	
Hollingworth	1923-24	Alcohol	6	(-)	7-14%
Whiting and English	1925	Fatigue Morning and evening	16	(o)	
Jersild and Thomas	1931	Adrenaline	6	(+)	Not significant.
Husband	1935	Interrupted sleep	1	(o)	
Carl and Turner	1939 1940	Benzedrine Benzedrine	143 38	(+)	Slight.
Edwards, A. S.	1941	Sleep privation (100 hrs.)	19 exper. 10 control	(o)	
		E. Two-plate, stylus			
Bagby	1921	Anoxia (rebreathing)	Many pilots	(o)	Until final stages.
Laird	1923	"Razzing"	8	(-)(?)	Least of any test used.
Eagleson	1927	Monthly periodicity	women	(o)	
Dorcus and Weigand	1929	Carbon monoxide	6	(o)	Practice effects

Table 2 (con.)

TAPPING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Slocombe and Brakeman	1930	% Accident rate	86 motormen	(o)	
Thornton, Holck and Smith	1939	Benzedrine	3	(+)	
		Caffeine	3	(+)	Slight.
Philip, B. R. (I, II, III IV, V)	1939 1940	Fatigue-tapping 6-7 hrs. to exhaustion	12		Analysis of tapping as high speed continuous work.
Jones et al	1941	Hours of driving	528 truck drivers	(-)	Most consistent relationship to hours of driving.
Reynolds and Shaffer	1943	Sulfonamides	73	(o)	
Keys et al	1943	Diets restricted	8	(o)	
"	1944a	in some B-complex	8	(o)	
"	1944b	vitamins	8	(o)	
"	1945	Restricted -161 days	8	(-)	When compared with improvement in control groups.
Brozek et al	1946	Acute deficiency - 23 days	8	(-)	In performance in acute deficiency period.
Taylor et al	1945	Fasting	4	(-)	
Keeton et al Mitchell et al	1946 1946	Cold - diet clothing	12	(-)	In cold affected differentially by diet.
Glickman et al	1946	Cold-diet Vit. B	12	(-)	With low B vitamin.
Gray and Trowbridge	1942	Standardization for drug studies	0		r= .95 - .98
Melton	1947	Normal (8 min. test)	N= 500		r= .94 - .96

Table 2 (con.)

TAPPING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		F. Two-plate, non-stylus, finger tapping			
Malmo and Finan	1944	Altitude	23		r = .94
		12,000		(o)	
		15,000		(+)	
		18,000		(-)	
		G. Two telegraph keys, with barrier between			
Stevens, S. S.	1941	Noise - 90 to 115 db.	5	(o)	
		H. Two hand complex tapping			
Birren and Fisher	1945 (6)	Standardization	(Article not seen)		
Consolazio et al	1947	CO_2 increase and O_2 decrease in sealed chambers	4-77	(o)(?)	No consistent trend. Improvement in normal air.
		I. Key tapping on downward movement, touched bar above on upward			
Warren and Clark	1937	Sleep privation (65 hrs.)	4 exper. 4 control	(-)	After 30 hrs. Recovery before end of period.
				(o)	No increase in "blocks".
		J. Not identified			
Tyler	1947	Sleep privation (24-112 hrs.)	(Not stated)	(o)	

higher altitude or longer exposures (Malmo and Finan 1944; Eckman et al 1945; Otis et al 1946; Rahn et al 1946; Rahn and Otis 1947). The sensitivity of tests of this type to altitude appears sufficient to yield superimposed effects resulting from dietary changes (Eckman et al 1945). A steadiness test has also been shown by Otis et al (1946) to be sensitive to graded effects of hypocapnia induced by a pneumolator at 30,000 feet. Studies of sleep privation are consistent in showing no decrement (Cooperman et al 1934; Edwards 1941; Tyler 1947) except when the subjects actually fall asleep over the test. Carbon dioxide excess coupled with oxygen decrease has been shown by Consolazio et al (1947) to yield a significant decrement, which, in the absence of controls, may be interpreted as an artefact of heavy breathing movements. Slight, though in some cases unreliable, decrements are shown as well under conditions of smoking (Hull 1924; Fisher 1927), carbon monoxide gas (Dorcus and Weigand 1929), hours of driving (Ryan and Warner 1936; Jones et al 1941), and dietary privations (Berryman et al 1947). The effect of noise on the steadiness function was indeterminate (Stevens 1941), as was that of 'verbal stress' (Melton 1947). Vibration, according to Coermann (1939) results in little impairment. Three related studies on the influence of low temperature showed a highly variable response decrement which might be interpreted as a physiological artefact due to finger stiffening. Additional effects are summarized in Table 3.

Reliability coefficients of steadiness have been generally reported as high. Kellogg (1932) gives an odd-even value of .94 - .98 (corrected); Paulsen (1935) reports an odd-even value of .98 (corrected) and a test-retest value of .73. The lower retest value is attributed by this worker to random individual variations rather than to learning. Malmo and Finan (1944) have shown that reliability of a multiple, arm-hand steadiness varies with size of hole, ranging from .88 - .97 (corrected). Test-retest values according to these workers vary between .43 - .84. Practice, according to their findings, is practically negligible. Melton (1947), using a one-hole technique, has calculated intratest reliability values at .76 - .85 (uncorrected). The test design which appears to incorporate most features of control is that of Melton (1947); as an additional advantage, his version has been standardized on more subjects than other tests. An interesting variant of this test involving the simultaneous use of the two hands has been developed by the same investigator and shown to be reliable under certain conditions of testing.

While the basic nature of the steadiness function remains obscure, intercorrelational data serve to shed some light on its characteristics. Melton (1947) reports a high ($r = .85$) degree of relationship between steadiness scores of the two hands measured simultaneously. Seashore (1940) reports a high correlation between hand tremor and stationary steadiness. In opposition to this finding is Melton's (1947) evidence that Air Corps candidates who showed obvious signs of tremor, as observed clinically, made average

or better-than-average scores on a steadiness test. The latter finding would appear to contrast the voluntary character of the steadiness function with the involuntary nature of tremor. Arm-hand steadiness is reported by Seashore (1940) to be positively related to other indices involving control of fixed movements, as postural sway, rifle muzzle sway, steadiness thrusting and target-shooting. Intercorrelational values of these measures with steadiness are .45 or higher. According to Melton (1947) correlations with complex coordination, two-hand coordination, discrimination reaction and finger dexterity are low. A factor analytic study reported by the same source, in which other tests of dexterity were compared with steadiness (time of contact), indicated that this function is loaded in a single factor which was not clearly defined. It was not loaded with dexterity or perceptual factors. Marking and dotting showed loadings similar to that of steadiness performance. According to the theoretical analysis of Brown and Jenkins (Fitts 1947) two components of static reactions which appear to be most significant are "the relatively minute, high frequency tremor movements, and the large, slow changes in static position". The chief importance of the present type of reaction appears a priori to lie in its relation to other complex adjustments which it makes possible. The need for studies investigating the influence of such variables as body member, position of limb, knowledge of results, as well as of other general factors presumed important to motor functions, on static steadiness reactions is indicated.

4. Tests of Body Sway

Steadiness of the body as a whole is measured by the ataxiameter. Of the several types of apparatus in fairly common use, the Miles (1922) ataxiameter is typical. This apparatus summates by means of automatic counters the anterior, posterior and lateral deviations of the head from a position determined by the fixed station of the subject. A modified ataxiameter developed by Edwards (1942) measures sway at hip and hand-arm level as well as at the level of the head. A more recent model (Fisher, Birren and Leggett 1945) simplifies the technique to measure anterior-posterior sway alone. Depending on the region of the body from which measurements are taken, differences in results may be found. In addition such factors as posture, height, weight, length of feet, presence or absence of visual cues and others must be accounted for in order to render comparable the results of different investigations.

Among the results arrayed in Table 4, those obtained under simulated altitude yield a well marked decrement (Barach, Brookes et al 1943; Biren, Fisher et al 1946). Vollmer et al (1946) have shown that effects are no more pronounced with a combined condition of altitude and carbon monoxide than with altitude alone. Allied to

Table 3

STATIC STEADINESS TESTS: A. PART REACTION SYSTEMS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		1. Arm-hand Steadiness			
Hollingworth	1912	Caffeine	16	(-)	Slight.
Hollingworth	1914	Diurnal variations	15	(+) (-)	Some evidence of diurnal variations.
Carver	1922	Smoking		(?)	
Muscio	1922	Normal	88 workers		Correlation with other motor tests low.
Laird	1923	"Razzing"	8	(-)	
Hollingworth	1923-24	Alcohol	6	(-)	
Hull	1924	Smoking	19	(-)	
Fisher, V. E.	1927	Smoking	4	(-)	
Eagleson	1927	Monthly cycle	4 women	(?)	Slight evidence of variation.
Glaze	1928	Fasting (10-33 days)	3	(-) (+)	During first week. As fast continued.
Dorcus and Weigand	1929	Carbon monoxide (3-5 hrs.)	6	(?)	Slight evidence of decrement on prolonged test but not statistically significant.

Table 3 (con.)

STATIC STEADINESS TESTS: A. PART REACTION SYSTEMS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Kellogg	1932	Emotional stimuli - snake, shock etc.	42	(-)	r (odd-even) = .94 - .98 After stimuli, greater variability.
		Controlled exercise		(-)	Greater than emotional, but quicker return to normal.
Swope	1933	Driving	14	(-)	Increased variability.
Kleitman	1933	Diurnal change	6	(+) (-)	Evidence of diurnal change, afternoon maximum.
Cooperman, Mullin, and Kleitman	1934	Sleep privation (60 hrs.)	6	(o)	
Hull	1935	Caffeine	16	(-)	11.2%
Husband	1935	Interrupted sleep	1	(?)	May be slight evidence of decrement.
Davis, R. C.	1936	Aspirin (10gr.)	33	(o)	
Ryan and Warner	1936	Long driving	6	(-)(?)	Tendency towards decrement; increased variability.
Thornton, Holck and Smith	1939	Benzedrine Caffeine	3	(+) (-)	Not reliable statistically.
Coerman	1939	Vibration (15-1000 Herz)	2-12	(o)	
Edwards	1941	Sleep privation (100 hrs.)	19 exper. 10 controls	(o)	
Jones et al	1941	Hours of driving	640 truck drivers	(-)	Progressive with hours of driving.

Table 3 (con.)

STATIC STEADINESS TESTS: A. PART REACTION SYSTEMS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Stevens, S. S. Wiener and Miller	1941(1) 1941(2) 1946	Noise - 90 and 115 db.	5	(?)	
Reynolds and Shaffer	1943	Sulfonamides	73	(o)	
Malmo and Finan	1944	Altitude	36		Little practice effect r= satisfactory, varies with size of hole.
		12,000 ft. 15,000 ft. 18,000 ft.		(-) (-) (-)	Progressive impairment with altitude. Test sensitive to altitude.
Eckman et al	1945	Altitude - Diet 15,000 ft. 17,000 ft.	4	(-)	Impairment greater with protein diet by 16% over impairment with carbohydrate diet.
Keeton et al	1946	Diet - clothing	12	(-)(?)	Variable.
Mitchell et al	1946	Cold ($-20^{o}F$)	12	(-)(?)	Decrement in cold was highly variable.
Glickman et al	1946	Diet-Vit.B & Cold	12	(o)	
Cogswell et al	1946	Diet deficient in B-complex -12 weeks	7	(o)	No decrement.
Berryman et al	1947	Continued B-Vit. restriction	7	(-)(?)	Some evidence of decrement as diet continued. Some improvement with supplementation. Individual variability.

Table 3 (con.)

STATIC STEADINESS TESTS: A. PART REACTION SYSTEMS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Otis, et al	1946	Hypocapnia	10	(-)	
Rahn et al	1946	(Hyperventilation at 30,000 ft.)			
Rahn and Otis	1947	Alveolar air composition	11	(-)	Correlation of performance with alveolar air composition.
		(12,000 ft. and higher)	8	(-)	Barely significant at 12,000 ft., progressively worse with continued exposure.
		Glucose ingestion at altitude	8	(-)	Glucose ingestion does not improve impairment at altitude
Tyler	1947	Sleep privation (24 to 112 hrs.)	(Not stated)	(o)	No consistent change unless test lengthened, then (-).
		Benzedrine		(+)	Some improvement with benzedrine.
		Barbiturates		(-)	Some evidence of poorer performance.
Consolazio et al	1947	CO_2 excess, O_2 decrease in sealed chambers and heat	4-77	(-)	Decrement probably due to heavy breathing. Significant improvement on recovery in normal air.
Tuttle	1949	Breakfast habit alteration	women	(-)	When breakfast omitted, considerable individual variation.
Paulsen	1935	Normal	97		r(odd-even) = .98 r(test-retest) = .73
		Practice		(o)	Considerable individual variation from test to test.

Table 3 (con.)

STATIC STEADINESS TESTS: A. PART REACTION SYSTEMS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Melton	1942	Normal	N= 328		r= .92 - .94 (intratest)
	1947	Normal	"		r(rt.-left hands) = .80 r(test-retest) = .75 (1 week)
		"Pressure" - verbal stress and distractions	N= 200	(+)(?)	r(split-half) = .90 - .92 correlation between pressure and non-pressure trials, r = .82. Scores better under pressure but not significantly.
2. Two-Hand Steadiness Test					
Melton	1947	Normal	N= 288		r(rt.-left hands) = .85 Left hand significantly poorer than right hand. r(intratest) = .95 No validity for selection.
3. Finger Steadiness Tests					
Bousfield	1932	Ergographic work	4		Rate, amplitude and irregularity of movement vary with degree of fatigue.
Edwards	1946	-	-		Apparatus description.

these results with altitude are the findings of Consolazio et al (1947) in which increased body sway was found as a result of extended exposures to CO_2 excess and oxygen decrease in sealed chambers; a significant improvement was, moreover, noted upon recovery in normal air. Inconsistent findings tending toward a decrement, at least under extreme conditions, have been reported to result from sleep privation (Lee and Kleitman 1923; Edwards 1941b; Cooperman et al 1934; Husband 1935; Tyler 1947). Two studies of driving agree in showing increased sway (Ryan and Warner 1936; Jones et al 1941). Among studies of drug effects, both alcohol (Miles 1924) and the barbiturates (Tyler 1947) are reported to increase body sway, the latter in sleep-deprived subjects, while benzedrine (Tyler 1947) has been found, also under the condition of sleep privation, to decrease sway. Results obtained under noise of 115 db. were indeterminate (Stevens 1941). Increased variability of response has been independently remarked by a number of investigators working under diverse conditions. Intratest reliabilities reported by Seashore, Buxton and McCollom (1940) for the Miles technique are .80 (standing) and .89 (sitting).

According to Fisher, Birren and Leggett (1945) the intratest reliability of their ataxiametric technique falls between .87 and .96 (4 min. and 8 min. test) under the conditions of study; the test-retest value is reported as .92. Their range of test scores appears adequate for sensitivity. Edwards (1942) reports his technique to be relatively insusceptible to practice effects.

The relation between results obtained in the two postures of sitting and standing is given by Seashore, Buxton and McCollom (1940) as .57. These investigators have shown a moderate correlation of scores of standing subjects with tapping scores. Intercorrelations of ataxiametric scores with simple reaction time and serial discrimination reaction (Seashore 1940) tend to be zero; and with pursuit rotor, highly negative (-.62). Studies of general motor functions reported by the same workers support the view of a group factor for steadiness, including body sway, interpreted as a precision factor since it includes a number of performances emphasizing accuracy of movement.

5. Steadiness Aiming and Tests of Static Equilibrium

The steadiness aiming test appears to differ from static-steadiness mainly in its greater emphasis on a movement factor which cooperates with steadiness in the joint determination of performance. In tests of the present sort a bodily member is moved from a fixed position to a prescribed position at a distance from the subject. Variations of the technique are distinguishable mainly on the basis of the bodily members and movement-coordinations required by the task.

Table 4

STATIC STEADINESS TESTS: B. BODY SWAY (ATAXIAMETER)

Code to results:
(-)= decrement (increase in sway); (o)= no change; (+)= increment (decrease in sway); (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Miles	1924	Alcohol		(-)	Dependent upon dosage.
Lee and Kleitman	1923	Sleep privation (60-114 hrs.)	1	(o)	No consistent effect.
Glaze	1928	Fasting (10-33 days)	3	(o)	No consistent effect.
Laslett	1928	Sleep reduction	5	(o)	No consistent effect.
Kleitman	1933	Diurnal change	6	(+)(-)	Indication of diurnal change.
Cooperman et al	1934	Sleep privation (60 hrs.)	6	(o)	
Husband	1934	Music and rhythm	156	(-)	All types of music increased body sway.
Husband	1935	Interrupted sleep	1	(?)	Tendency toward greater amount of sway.
Ryan and Warner	1936	Long driving (8-1/2 hrs.)	6	(-)	Also greater variability.
Skaggs	1937	Tensing muscles of legs	25 (women)	(-)	Greater sway with tensed leg muscles.
Edwards	1941	Sleep privation (100 hrs.)	19 exper. 10 control	(-)	Very irregular.
Jones et al	1941	Hours of driving	272	(-)	Progressive decrement with hours of driving.

Table 4 (con.)

STATIC STEADINESS TESTS: B. BODY SWAY (ATAXIAMETER)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Stevens, S. S.	1941	Noise - 90 and 115 db.	5	(?)	
Edwards	1942	Age	1400	(+)	From age 3 to 20. After that no change.
		Feeble-minded and insane		(-)	Great variability.
		Smoking		(o)	
		Music		(-)	
		Practice		(o)	Little to no improvement.
Barach, Brooks et al	1943	Altitude (15,000 ft. for 1-3/4 hrs.)	16	(-)	At altitude, emotionally impaired group showed slightly greater decrement than emotionally unimpaired.
Birren, Fisher et al	1946	Altitude 10,000; 14,000 15,500, 18,000 ft.	29	(-)	No decrement at lower altitudes. Marked increase in subjects about to collapse. Individual variations.
Vollmer et al	1946	Altitude as above + carbon monoxide	17	(-)	Impairment no greater than with altitude alone.
Consolazio et al	1947	CO_2 excess and O_2 decrease in sealed chambers	4-77	(-)	Decrement improved significantly on recovery in normal air.
Cogswell et al	1946	Diet deficient in B-complex and animal proteins.	7	(o)	No decrement in 5 weeks.
Berryman et al	1947	Diet continued for 15-18 weeks, then supplemented.	7	(o)(?)	Individual variability but some decrement; improvement with supplements.

Table 4 (con.)

STATIC STEADINESS TESTS: B. BODY SWAY (ATAXIAMETER)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Tyler, D. B.	1947	Sleep privation (24-112 hrs.)	65	(-)(?)	Some decrement but not significant.
		Benzedrine		(+)	Prevents deterioration.
		Barbiturates		(-)	Increased decrement.
Fisher, Birren and Leggett	1945	Normal	133		r (test-retest) = 0.92 r (split-half) 4 min. = 0.87 8 min. = 0.96
Fisher	1946	Normal	Same		No change with age of subjects.
Seashore and Adams	1933	Normal			These studies give data on standardization, relationship of this test to other psychological tests, to practice, visual cues, anthropometric measures, etc.
Humphreys et al	1936	"			
Seashore	1940	"			
Seashore, Buxton and McCollom	1940	"			
Travis	1945	"			
Edwards, A. S.	1946	"			
Henmon	1919	Normal	Aviation personnel and candidates		These studies concur in in finding no correlation between body sway and flying ability.
Stratton et al	1920	"			
Miles	1922	"			
Brammer	1925	"			
McFarland & Franzen	1943	"			

The standard tests of steadiness-aiming may employ the same apparatus or one closely similar to that used in the steadiness test. The subject may thrust a stylus or direct a pivoted stylus, into a hole or a series of holes. Scores are taken in terms of 'misses' which are recorded by a counter or a cumulating device, actuated by contact of the stylus with the area immediately surrounding the target. Descriptions of representative techniques are given by Whipple (1914), Dunlap (1921), Seashore and Adams (1933), Malmo and Finan (1944), and Melton (1947). Factors necessitating standardization are closely allied to those discussed under steadiness testing. The technique of Melton appears to incorporate the greatest number of features of control.

With a single exception, use of tests of this type had been limited to the condition of altitude, which has yielded consistent deficit in performance (Bagby 1921; Grether and Smith 1942; Gagne and Smith 1943; Loucks 1944; Malmo and Finan 1944). According to the findings of Malmo and Finan (1944) steadiness-aiming proved to be less sensitive as an index of anoxia than stationary steadiness. Impairment was not increased when subjects receiving sulfadiazine were subject to altitude. A decrement in performance was found by Ryan and Warner (1936) following prolonged driving of an automobile.

Reliability coefficients reported for this test are substantially similar in value to those obtained with tests of static steadiness uncomplicated by aiming movements. Malmo and Finan give an intratest reliability range from .66 - .80 (corrected) for their version of the test. Somewhat higher values are given by Melton for his technique: .92 - .96; however, reliability diminished from a test-retest value of .76 at ground to .32 under actual testing conditions involving altitude. That steadiness-aiming is somewhat more susceptible to practice than static steadiness is borne out by the data of Grether (1942) as well as by that of Malmo and Finan (1944). Grether further notes high variability of performance and a wide range of scores on his test.

As a step toward interpreting the steadiness-aiming function, Melton has shown a high correlation (.66) between steadiness-aiming and stationary steadiness. It may be significant that the steadiness-aiming test proved to have low validity for the prediction of success in pilot training (Melton 1947); nor was its correlation with this criterion improved by adding 'verbal stress', a change which apparently did not alter the character of the test. Intercorrelations reported by the same investigator between steadiness-aiming and other tests under altitude conditions were: .20 with single dimension pursuit test, -.04 with peg moving, .21 with addition and .06 with code substitution.

The factorial composition of the steadiness-aiming function appears to be similar to that of stationary steadiness (Seashore 1940). A final interpretation of the relationship between the two functions must, however, await more complete evidence, since tests have not,

for the most part, been designed to separate those components which on common-sense grounds appear to differentiate 'static' from 'positioning' reactions.

Tests of Dynamic Equilibrium

Tests falling under the category of dynamic equilibrium appear to bear somewhat the same relation to steadiness-aiming as tests of body sway do to static-steadiness. Examples are provided by the 'Wobblemeter' described by Hunt (1936) which involves keeping the balance while standing on a small platform, and the 'stabilometer' developed by Travis (1944a). McFarland and Barach (1937) in attempting to distinguish between performance of normal and psychoneurotic subjects under anoxia, found the 'wobblemeter' to be unsuitable for the purpose since many of the subjects became too dizzy to take the test.

According to Travis (1945) little relationship exists between measures of static and dynamic equilibrium. He also reports little or no correlation between stabilometer performance and pursuit. Center of gravity of the body is proposed as a unique factor measured by the present type of test, and not by tests of static equilibrium.

6. Aiming, Spearing and Allied Tests

Closely allied to tests of steadiness-aiming, is a second group concerned with accuracy of movement, which includes such varied performances as aiming at a target with a spear, dart throwing, rifle shooting, ball tossing, and three hole coordination. The hypothesis might be ventured that this group of varied tests differ from those of steadiness-aiming chiefly in their allowance of greater freedom of movements of the 'positioning' type.

The Whipple Target Test (1914) involves striking at small crosses, randomly placed on a target, with a pencil held in the subject's hand. The Muscio Spearing Test (1922) differs mainly in the substitution of a small spear for the pencil and the use of concentric circle targets. In the dart-throwing test the subject attempts to hit the center of a target from a prescribed distance. Ball-tossing with both hands has also been used as a measure of complex aiming-throwing coordination.

Except for the study of Jones et al (1941), who found a non-graded decrement in target-aiming after long hours of driving, and that of Tyler (1947), who demonstrated impairment on a prolonged rifle marksmanship test with severe sleep privation, results obtained with tests of the present type have been uniformly indeterminate or negative. Reliability appears to be difficult to achieve with these tests because of relatively large and continued

Table 5

STEADINESS - AIMING TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Steadiness aiming (Dunlap)			
Bagby	1921	Anoxia (rebreathing)	272	(-)	Constant but irregular beginning at 17.3% O_2.
		B. Swope-Whipple with visual cues			
Ryan and Warner	1936	Driving (8-1/2 hrs.)	6	(-)	Also greater variability.
		C. Steadiness-thrusting (Finan-Malmo)			
Malmo and Finan	1944	Altitude			Some practice effect.
		12,000 ft.		(o)	Test not so reliable,
		15,000 ft.		(-)	nor so sensitive as
		18,000 ft.		(-)	stationary-steadiness.
		D. Steadiness Aiming (CM103E)			
Grether[1]	1942	Altitude 18,000 ft. - 15 min.	36		r (intratest) = satisfactory. Learning present and slow in reaching plateau.
Grether and Smith[1]	1942	"	16 - 24	(-)	
Gagne and Smith[1]	1943	"	26	(-)	
Loucks[1]	1944	"	36	(-)	Satisfactory r (test-retest) at ground level, not at altitude.
Campbell (Loucks)[1]	1944	Altitude plus sulfadiazine	18	(o)	Impairment with altitude not changed by drug.

[1] Data is summarized in Melton (1947).

Table 5 (con.)

STEADINESS - AIMING TESTS

Source	Year	Condition	Subjects	Code	Results: Remarks
Melton	1947	Normal testing	N = 2000 N = 776		r(intratest) = .92 - .96. Correlation with Arm-Hand Steadiness, r = .66.
		"Stress"[1] verbal stress or distracting mental activities	N = 386 N = 654	(?)	r (test-retest) = .86. Higher test scores on "stress" trials significant but small.
E. Various (stylus and photoelectric aiming) tests					
Seashore and Adams	1933	Normal testing			Give data on reliabilities, test intercorrelations and relation to marksmanship.
Humphreys et al	1936	"			
Seashore, R. H.	1940	"			

[1] Pattern of scores in successive trials under "stress" is not the same as for steadiness aiming without stress.

practice effects (Muscio 1922; Landis 1935). Seashore (1940) has reported correlations of rifle muzzle sway during sighting, and marksmenship, with indices of steadiness in highly practiced subjects. That these tests are highly susceptible to motivational factors, such as knowledge of results, competition, and standards set by the experimenter, has been demonstrated by Mace (1935). A possible advantage claimed for this type of test is, however, that they generate more interest than many other types of test.

The 'three-hole test' is a variant of the present group of tests which requires that the subject insert a stylus successively, as rapidly as possible, into each of three holes arranged in a triangular pattern on an inclined panel. Scores are recorded automatically by counters each time a contact is made between hole and stylus. The few studies found which made use of this test showed the following tendencies: impaired performance with alcohol (Hollingworth 1923-24) and with 'razzing' (Laird 1923); indeterminate results with caffeine (Hollingworth 1912), and with administration of oxygen to dementia praecox patients (Hinsie, Barach et al 1934). Garrett and Schneck (1933) report that intercorrelations of scores on the three-hole test with other sensori-motor performance depends on the stage of practice; the correlation with tapping is reported to rise from -.25 for the first trial to .39 for the two hundred and fifth trial. Reliabilities for this test, ranging from .50 - .93, have been found in the literature (Stecher 1916; Garrett and Schneck 1933).

7. Tests of Manipulation and Dexterity

Techniques classed under the category of 'manipulation and dexterity' require combined precision and speed of performance. Such tests are limited to serial eye-finger, eye-hand, and eye-arm coordinations, or to combinations of these. Usually they involve a minimum of complication on the stimulus side. On the level of test operations, these may be grouped according to the type of material manipulated, as, for example, pegs, balls, blocks, and the like.

In conventional peg-moving tests, a number of small pegs must be placed by the subject into a series of snugly fitting holes as rapidly as possible (Barach, Brookes et al 1943), or moved from one series of holes into another (Russell 1948), or removed, rotated and replaced, in the same holes as in the Santa Ana finger dexterity test (Melton 1947). The score is determined by the number of seconds required to complete the test, or by number of pegs manipulated in a unit time as well as by number of errors made. In a variant form of the test (SAM Peg-moving Test) reported by Melton (1947) a complication was added to the simple placing test requiring the subject to insert the triangular end of a peg into a hole of corresponding shape, remove the peg, rotate it through 180° and then to insert the other end,

Table 6

AIMING, SPEARING AND ALLIED TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = Increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Aiming at target (spearing at target)			
Muscio	1922	Long work on test itself (2 hrs.) Rate of work varied.	6 (trained)		Inaccuracy (decrement) is function of rate of performance rather than of duration of performance.
Robinson and Herrmann	1922	Sleep privation (60-65 hrs.)	3	(o)	No consistent effect.
Lowson	1923	Altitude	5 (trained)	(?)	Number of observations too small to be reliable.
Sowton and Myers	1928	Monthly periodicity	29 women	(?)	Very complex results.
Mace	1935	Incentive	(various)		Performance depends upon standards adopted by subject and upon explicit instructions or knowledge of results.
Edwards	1941	Sleep privation (100 hrs.)	19 exper. 10 control	(?)	
Jones et al	1941	Hours of driving since sleep	650 truckdrivers	(-)	In drivers vs. non-drivers. No progressive effect with hours of driving.
		B. Dart throwing			
Johnson, B. J.	1922	Fatigue (children)	15 (trained)	(?)	Long practice curve.
Bates	1922	Smoking	8	(?)(-)	May be slight.
Carver	1922	Smoking	Trained	(?)	

Table 6 (con.)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Landis	1935	Adrenaline	7 (trained)	(o)	Questions value of test.
		C. Ball tossing into basket			
Weiskotten and Ferguson	1930	Sleep privation (3 days)	3 exper. 2 control	(?)	
		D. Marksmanship			
Stevens, S. S.	1941	Noise of 90 & 115 db.	5 (trained)	(o)	
Tyler	1947	Sleep privation (24-112 hrs.)		(o)	On short test.
				(-)	On longer test.
		Benzedrine		(+)	On longer test.
		E. Three-hole test			
Hollingworth	1912	Caffeine	16	(?)	Slight increment which might be followed by loss.
Hollingworth	1914	Diurnal variations	15	(+)(-)	Some evidence of diurnal change.
Stecher	1916	Humidity	Groups		Complex results.
Hollingworth	1923-24	Alcohol	6	(-)	Proportional to dosage.
Laird	1923	"Razzing"	8	(-)	
Hinsie, Barach et al	1934	Oxygen administration	10 dementia praecox	(?)	

Table 6 (con.)

AIMING, SPEARING AND ALLIED TESTS

Source	Year	Condition	Subjects	Code	Results Remarks
		F. Various aiming tests			
Seashore and Adams	1933	Rifle target shooting and other aiming tests under normal conditions	Various groups included expert marksmen		Correlation was found between scores on marksmanship and simpler aiming and steadiness.
Humphreys et al	1936				
Seashore, R. H.	1940				

which was pentagonal, into an appropriately shaped hole. Finally a push-button is pressed which lights a lamp, signaling the completion of the unit-task. The score is obtained by taking the number of complete sequences in a given time.

Whereas tests of the type described immediately above are self-paced; i.e., the subject determines his own speed, a test in which the pacing is determined automatically by the apparatus was developed by Pollock and Bartlett (1932). Each time a constant speed trolley, moving back and forth every few seconds, approaches the subject, a peg is removed from or replaced on a board mounted on the trolley. In a more complex version, two trolleys on separate tracks move in alternate phase in relation to the subject. The task is to remove a peg from one trolley and replace it in a hole on the platform of the other trolley, removal or replacement being performed only when the trolley is in the position nearest to the subject.

A test based on a somewhat different principle, involving coordinated movements of the two hands involves dropping a ball-bearing successively as rapidly as possible through a pipe held vertically in front of the subject (Brozek 1944). A mechanical counting device summates the number of times the ball passes from the top to the bottom of the pipe. Also based on manipulation of balls is the 'psychomotor coordination test' (Weiner and Hutchinson 1945) in which the task-requirement is to pick a number of small balls off a rotating disc, with a pair of forceps.

Manipulation of cubes is utilized in the Minnesota block test (Green et al 1945). The task-requirement is to replace a number of blocks, one at a time, into a box designed to hold four layers of 49 blocks each. Scores are derived from the number of units replaced in 90 seconds, or, in terms of total time consumed in replacing all of the blocks.

Table 7 summarizes results obtained with manipulation and dexterity tests under the varied environmental conditions listed. Results at simulated high altitudes justify the conclusion that performance is impaired to a small extent under relatively extreme conditions (Grether and Smith 1942; Gagne and Smith 1943; Loucks 1944; Green 1947; Russell 1948). That these tests do not appear sufficiently sensitive to detect deficit with lower altitudes may be suggested by the findings of Barach, Brookes et al (1943), Smith, Seitz and Clark (1946), and Smith (1948). In line with such a view is Russell's (1948) finding of rapid compensation for the initial deficit during a 35 min. stay at 18,000 feet. Jones et al (1941), using a "reach and grasp" test demonstrated a rapid and consistent decline in performance as hours of driving increased. Pollock and Bartlett (1932) demonstrated impairment resulting from regular noises occurring asychronously with the subject's operations while performing on the double-trolley test. Prolonged Vitamin-B deficiency (Brozek et al 1946), and fasting (Taylor et al 1945) have been shown to be associated with impairment. Additional findings are given in Table 7.

Grether and Smith (1942) and Gagne and Smith (1943) give intratest reliability coefficients of .83 to .90 (corrected) for the SAM Peg-Moving Test. Intertest reliabilities for the same technique are reported as considerably lower, .50 (trials 1 and 2) and .28 (trials 2 and 3). For the Santa Ana Finger Dexterity Test, Melton (1947) reports an intratest value of .93, and high test-retest values. Corrected intratest reliability of the arm-hand coordination test is given as .87 - .89. Brozek (1944) has found that the intratest reliability of the ball-pipe test ranges from .70 - .80 (uncorrected). In view of the evidence considered above it appears that tests of the present type are reasonably consistent measuring instruments.

Few clues are available as to the nature of the psychological functions sampled by these tests of dexterity. A battery of five tests of the present type analyzed by Melton (1947) yielded intercorrelations ranging from .28 - .61. In this study it was further demonstrated that there were no relationships between the tests of dexterity employed, and tapping, steadiness, discrimination reaction-time, and cancellation. A dexterity factor common to performance on various peg-moving tests has been suggested by Melton (1947).

8. Path-tracing tests

Presumably related to tests of manual dexterity but differing in the significant respect that they involve continuous movements of a less repetitive sort, are the path-tracing tests. In tests of this type the subject must move a stylus or pencil more or less precisely and continuously along a narrow slit bounded on both sides. Thus, continuously changing motor adjustments, in response to continuously changing patterns of stimulation, are demanded for proficient performance on these tasks. Movements may be linear or curvilinear, discrete or cursive, toward or away from the body, to the right or left, with the preferred or non-preferred hand. Scores are derived from the number or duration of contacts made with the sides during the tracing of the length of prescribed course, or occasionally, by noting the first point of contact. For details of apparatus and technique employed in path-tracing tests, the reader is referred to Whipple (1914), Garrett and Schneck (1933), and Gurnee (1939). Certain simple maze-patterns (Vernon 1926) in which perceptual requirements are held at a minimum do not appear to differ in any important respect from other tests falling within the present group. Depending on the aspects of performance selected for analysis, 'mirror-tracing' tests may properly be classified under the present heading, or may represent more complex types of performance to be discussed later in the report. (See tests of 'change of set' and learning.)

The 'rail-walking test' developed by Fisher and his co-workers (1946, 1947) may be considered analogous to the tracing test, although it differs from those considered above in that movements of the entire

Table 7

TESTS OF MANIPULATION AND DEXTERITY

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Code	Results: Remarks
		A. Tests involving the manipulation of pegs			
		1. Peg-placing with forceps			
Barach, Brookes et al	1943	Altitude 15,000 feet	16	(o)	Impairment not marked.
		2. Peg moving			
Griffin, D. R.	1944	Gloves for cold	(Not reported)		Standardized method to express dexterity decrement while wearing gloves.
		3. SAM Peg Moving Test (CM127A,B)			
Grether[1]	1942	Standardization for altitude testing	24		Test-retest (1 vs.2), r= .50 (2 vs.3), r= .28
Grether and Smith[1]	1942	Altitude 18,000 ft. - 15 min.	24	(-)	Small but significant r(odd-even) = satisfactory.
Gagne and Smith[1]	1943	"	13	(-)	
Loucks[1]	1944	"	36	(-)	Not so significant as other tests in the battery.
Campbell (Loucks)[1]	1944	" plus sulfadiazine	36	(o)	No additional impairment with drug.
Melton	1947	Normal testing	363		Low correlation with success in bombardier training.

[1]Data is also summarized in Melton (1947).

Table 7 (con.)

TESTS OF MANIPULATION AND DEXTERITY

Source	Year	Condition	Subjects	Code	Results Remarks
		4. Santa Ana finger dexterity test (CM116A)			
Melton	1947	Normal testing	(Large groups) AAF candidates		Reliabilities high. No validity for selection of pilots.
Russell	1948	Anoxia - 18,000 ft. (35 min.)	67	(-) (+)	Initial decrement followed by rapid adjustment and improvement with practice.
		5. Arm-hand coordination			
Russell	1948	Anoxia - 18,000 ft. (35 min.)	81	(-) (+)	Results similar to test above.
Melton	1947	Normal testing	(Not stated)		r (intratest) = .87 - .89
		6. Trolley and Double-trolley tests			
Pollock and Bartlett	1932	Noise			
		Regularly occurring, non-synchronous clicks		(-)	
		Irregular loud noises		(o)	Little effect after initial disturbance.
		B. Tests involving the manipulation of small balls			
		1. Ball-Pipe Test			
Brozek	1944	Standardization	200		r (intratest) = .7 to .8 (uncorrected)

Table 7 (con.)

TESTS OF MANIPULATION AND DEXTERITY

Source	Year	Condition	Subjects	Code	Results Remarks
Keys et al	1943 1944 a 1944 b 1945	Vit. B-Complex deficient diets over extended periods - 161 days followed by acute deficiency	8 8 8 8	(o) (o) (o) (o)	Little change with partial restriction, but decrement in acute deprivation is significant (t approaches 1% level).
Brozek et al	1946		8	(-)	
Taylor et al	1945	Fasting - 5 successive periods of 2-1/2 days	4	(-)	Trend towards less impairment on 5th fast as compared with 1st fast.
2. Psychomotor coordination Test - Picking balls off rotating disk with forceps.					
Weiner and Hutchinson	1945	Heat and humidity		(-)	8% decrement - due to slower time and greater inaccuracy.
C. Tests involving the manipulation of blocks. 1. Minnesota rate of manipulation test.					
Reynolds and Shaffer	1943	Sulfonomides	24 Army 49 students	(o)	
King et al	1945	Diet and altitude 17,000 ft.	10	(-)	Decrement greater with protein diet or fasting for 6-1/2 hours.
2. Cube placing (Block test).					
Green et al	1945	Diet and altitude 17,000 ft.	50	(-)	Protein diet significantly lower (1% level) than carbohydrate.
Green	1947	Altitude 17,000 ft.	50	(-)	No correlation between impairment in this test at altitude and impairment with other tests in battery.

Table 7 (con.)

TESTS OF MANIPULATION AND DEXTERITY

Source	Year	Condition	Subjects	Code	Results Remarks
Smith, Seitz and Clark	1946	Altitude 10,000 ft. 7-1/2 hrs.	15	(o)	
Smith, G. M.	1948	"	16	(o)	
Brozek et al	1946	Vit. B-complex acute deficiency	8	(?)	Slight decrement but not significant ($t = 2.14$)
D. "Reach and Grasp" (Pencil shifting) (Reaction - Coordination)					
Miles	1931 a	Normal	100		Mean time = 1.21 sec. right hand. 1.36 sec. left hand.
Miles	1931 b	Normal	335 men 528 woman		Increase with age.
Jones et al	1941	Hours of driving	659 truck drivers	(-)	Rapid and consistent decline as hours of driving increase.
Keeton et al Mitchell et al	1946 1946	Diet - cold clothing	12	(-)	With cold. Dietary effect confused.
Glickman et al	1946	Diet - Vit. B-cold	12	(o)	No effect of Vit. B. Cold effect not clearly stated.

body are involved. The subject is required to walk a raised rail 1 inch wide and 10 feet long, placing heel to toe, and keeping the hands clasped behind the back. Performance is scored as the sum of distances walked in 10 trials. In the single study employing this test to detect possible decrement, Consolazio et al (1947) observed no impairment in performance with oxygen decrease and carbon dioxide excess in sealed chamber. Standardization data on naval personnel are given by Fisher (1946) who reports a moderately high intratest reliability, .77 (corrected) for first trial; .85 for second trial for the test, although a marked practice effect has been observed. Scores on the 'rail-walking test' as determined in the same study do not correlate with ataxiametric scores obtained on 43 subjects.

In Table 8 are shown, in summary, effects of a variety of conditions on path-tracing performance. McFarland and his co-workers (1937, 1937-II) have shown a decrement in mirror tracing to result from exposure to simulated altitude. Keeton and his co-workers (Keeton et al 1946; Glickman et al 1946; Mitchell et al 1946) have reported a decrement in performance in the cold but their reported evidence does not permit assessment of the influence of the additional factors of clothing and diet. In the acute phase of Vitamin-B restriction, Brozek's (1946) subjects showed impairment on a pattern tracing test, a result which was paralleled by Taylor et al (1945) with fasting subjects. Otherwise results obtained under such diverse conditions as sleep privation (Husband 1935), oxygen administration (Hinsie et al 1934), and restricted diets, were mainly negative or indeterminate.

Garrett and Schneck (1933) give the reliability of the standard Bryan tracing board as .93 as measured on extended performance of children. For his form of the tracing-board, Gurnee (1939) reports uncorrected odd-even reliability coefficients of .82, for performance with the right hand, and .77, with the left. The relatively great sensitivity of these tests to practice is generally agreed on by workers who have used it. That mirror-tracing is especially susceptible to learning is attested by its frequent use in experiments designed to investigate changes in behavior resulting from practice.

Seashore (1940) obtained a correlation of .30 $\pm$ .09 between precision of thrust, and steadiness in tracing a narrow V-slot. The representativeness of this single coefficient is, however, not established. No study of factorial composition of path-tracing performance has been found.

Table 8

PATH-TRACING TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Bryan tracing board.			
Hinsie et al	1934	Oxygen admin.	10 (dementia praecox pts.)	(?)	
Husband	1935	Interrupted sleep	1	(o)	
Gilliland & Nelson	1939	Coffee	5	(-)(?)	Some indication of decrement.
		B. Gurnee - Inverse S.			
Gurnee	1939	Normal	45		r(intratest)= .86 -.90 corrected.
Keeton et al Mitchell et al	1946 1946	Cold - diet -clothing	12	(-)(?)	Reported decrement in cold. Effects of diet and clothing difficult to assess.
Glickman et al	1946	Cold & Vit.B diet	12	(o)	No effect of Vit. B alone or in cold.
		C. Pattern tracing test.			
Keys et al	1943	Restricted thiamine	8	(o)	
	1944 a	Restricted riboflavin	6	(o)	
	1944 b	Restricted B-complex (40 days)	8	(o)	
	1945	Restricted B-complex	8 (trained)		30 preliminary practice periods.
		161 days - partial		(o)	
		23 days - acute		(-)	
		10 days supplemented		(+)	Decrement only during acute deficiency
Brozek et al	1946	Same	Same	Same	

Table 8 (con.)

PATH-TRACING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Taylor et al	1945	Fasting - 5 successive 2-1/2 day fasts at intervals of 5-6 weeks	4 (trained)	(-)	Decrement in all fasts, but better performance in 5th than in 1st.
Franklin & Brozek	1947	Concentrated vs. distributed practice	36	(o)	No difference in learning efficiency.
		D. Maze tracing tests.			
Dunlap	1918	Alcohol	2	(?)(-)	
Vernon	1926	Repetitive work on task itself	1		Analysis of work output and accuracy.
		E. Mirror tracing.[1]			
Kleitman	1933	Diurnal change	6	(+) (-)	Optimum in afternoon.
McFarland	1937-II	Altitude (acclimat.)	1 (trained)	(-)	
McFarland & Barach	1937	Altitude	25 normal 30 psychoneurotics	(-)	Greater decrement with psychoneurotics.
Snoddy	1920 1926	Normal Normal			Test description and learning curve analysis.
Melton	1947	Normal			Test unsuitable for mass testing.

[1] Other references on mirror drawing are discussed under "change of set" tests.

Table 8 (con.)

PATH-TRACING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		F. Rail-walking test.			
Heath	1943	Normal testing	Army		Discussion of usefulness of test in diagnosing awkwardness.
Fisher, Birren & Leggett	1945	Standardization	151		r(odd-even)= .77 - .85 r(test-retest)= .67 (one week)
		Practice - 4 days	18	(+)	78% improvement. No correlation with body sway.
Consolazio et al	1947	CO_2 excess, O_2 decrease in sealed chambers (heat)	4-77	(o)	

9. Dotting Tests

In advance of empirical information which permits a more fundamental classification of 'dotting' behavior, it may tentatively be considered to have components of both steadiness-aiming and pursuit performance. A distinction between dotting tests and path-tracing tests considered above, lies in the determination of the rate of performance by the apparatus, in the former, and by the subject himself in the latter. In the Schuster (Farmer and Chambers 1926) modification of the McDougall dotting test, which is considered representative of this type, the subject inserts a stylus in and out of as many as possible of a series of small holes arranged in a sinuous pattern on a disc rotating in a horizontal plane. The holes appear in a small aperture which at first exposes only one, but with the increasing speed of presentation during the latter part of the trial, exposes several holes at a time. Scoring is made automatic by an electrically operated counter which summates the total number of successful insertions of the stylus into the holes during a three minute run.

Examination of Table 9 reveals that dotting performance has proved sensitive to the condition of simulated altitudes of 15,440 feet and higher, but showed no significant decrement at 9,200 feet (McFarland 1937 I, 1937 II, 1938). Further, an increased decrement is reported to result from ingestion of alcohol at altitude. Other results are summarized in the table.

The intratest reliability of a dotting test investigated by Melton (1947) is reported as .95 (corrected) for the entire test. Susceptibility of dotting behavior to practice has been repeatedly observed.

The dotting test has been shown by Melton (1947) to be only slightly correlated with pilot success. Farmer and Chambers (1926, 1929, 1939) have shown a positive relationship between high scores on the test and low accident rate in driving as well as in certain industrial jobs. A fairly high correlation between dotting and two-plate tapping is reported by Melton (1947).

10. Pursuit Tests

Tests classed as 'pursuit' tests have in common the presentation of one or several visual displays, which move in one or more dimensions as determined by the apparatus, the subject, or both, and which must be followed or guided by the subject by means of continuous movements of the hands, feet or other members of the body, working singly or cooperatively. Pursuit tests, like those of dotting, are 'apparatus paced'. A number of types of pursuit test are distinguishable on the basis of what appear to be significant

Table 9

DOTTING TESTS (McDOUGALL-SHUSTER)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Smith, M.	1916	Sleep privation - fatigue	(few)	(-)	Useful instrument for studying fatigue.
Smith, Culpin & Farmer Culpin & Smith	1927 1930	Telegraphist's cramp and nervous tendencies	Groups of industrial workers		Poorer scores in psychoneurotics, except for obsessionals, with excellent scores.
Sowton & Myers	1928	Monthly periodicity	29 women	(o)	No consistent trend.
Farmer & Chambers " "	1926 1929	% industrial accident rate in industry	650 200 - 1800		Good scores correlate with low accident rates.
Farmer, Chambers & Kirk	1933	"	414		Test used in accident-prone battery because of its consistent relationship.
Farmer & Chambers	1936	"	(large groups)		
Farmer & Chambers	1939	Accident rate in drivers	(large groups)		
McFarland & Forbes	1936	Altitude and alcohol	2	(o)	Variability.
McFarland	1937-I	Altitude - rapid ascent - 14,890 ft.	6	(-)	Increase in variability.
McFarland	1937-II	9,200 ft. 15,440 ft. 17,500 ft. 20,140 ft.	10 10 9 5	(o)(?) (-) (-) (-)	Decrement progressive with increasing altitude.
	1937-IV	17,500 ft.	35 native workers at altitude and at sea level	(o)	

Table 9 (con.)

DOTTING TESTS (McDOUGALL-SHUSTER)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
McFarland & Barach	1936	Oxygen and alcohol	23	(-)	Reliable difference between effect of alcohol in air and in high O_2.
McFarland	1938	Altitude	30 normal 35 psychoneurotics	(-) (-)	Greater in psychoneurotics.
McFarland & Franzen	1943	Normal	Pensacola aviators		Low correlation with success in pilot training.
Melton	1947	Normal	N=513		r(intratest)= .88 (2nd half). r(intratest)= .91 (whole) (uncorrected) Low positive correlation for selection.
Dotting machine.					
Laird	1933	Continuous work on machine - 4 hrs. Noise varying in pitch and loudness.	4	(-)	Decrement in output, depending upon pitch, complexity and loudness of noise.

variations in the principles underlying the tests. Depending on whether or not the subject is enabled to control the motion of the display, the task is characterized as compensatory or non-compensatory. In the former type, the subject's efforts to compensate for deviations of the target from a prescribed position influence its behavior; in the latter case, movement of the target is determined entirely by the nature of the mechanical arrangements of the apparatus in independence of the subject's efforts. A second difference between pursuit tests relates to the number of spatial dimensions through which the target moves: whether in a plane to the right or left, or up and down, or forward and backward, or any combination of these. Pursuitmeters are classified as single- or multiple-dimensional according to the degrees of freedom of movement of the presentation and of the controlling devices. A third important way in which versions of pursuit tests differ is in the rate of movement of the display: whether at a uniform or periodic, or at a variable or aperiodic rate. Within the 'variable' type of pursuit test a further distinction is made between 'rate' pursuit tests in which the speed of movement of the 'follower' within a non-compensatory pursuit task, varies with the magnitude of the subject's response, in contrast with the 'direct' type in which the rate of movement of the follower remains constant. A distinction must be made, too, between tasks which require the use of a single hand and those which depend on the simultaneous coordination of both hands. While it would be misleading to urge that these differences as listed complete the possible varieties of pursuit tests, it is believed that they are sufficient for purposes of preliminary analysis. The following descriptions of tests exemplify the distinctions made immediately above:

(1) Non-compensatory, uniform, pursuit. The widely employed Koerth pursuit rotor falls within this category. The subject is required to keep a hinged (pressureless) stylus in contact with a small brass target embedded near the outside rim of a rotating disc. Scores are derived from the number of fractional revolutions during which the stylus is held on the target. The SAM rotary pursuit test is an adaptation of Koerth's test differing mainly in size of target, size and kind of disc, and rate of rotation. Differences in performance on the two tests are discussed by Melton (1947).

(2) Non-compensatory, variable, direct, pursuit. The principle of moving a visual target at an unpredictably variable rate of speed is the basis of a test reported by Farmer and Chambers (1926). A pointer controlled by the subject must be controlled in such manner as to keep it in line with a second pointer whose direction and rate of movement are determined by an irregular cam. Deviations of the 'follower' from the target are cumulated automatically to yield a score. Modifications of this technique have been employed by McFarland and his co-workers (1932, 1936).

(3) Non-compensatory 'rate' pursuit. Examples of this are reported by Melton (1947). Since the task involved in these tests appears to represent a highly specialized type of function, the rationale of which lies in its presumed similarity to the job of flying, it is not described here in detail. The Skilled Response Test, a composite task with a 'rate pursuit' component has been utilized in decrement-testing by the Cambridge group (Davis 1948) and is discussed later. (See Table 25)

(4) Non-compensatory, two-hand, pursuit. The SAM Two-Hand Coordination Test (Melton 1947) differs from pursuit tasks described up to this point in the requirement that the two hands be employed simultaneously in order to perform the task. Two lathe-like control handles are manipulated to keep a target follower on a visually perceived target moving at varying rates along an irregular pathway. Time spent off the target is cumulated by a clock to yield a score. Alternative scoring possibilities, such as 'smoothness of control', and an 'activity tension measure' have been investigated by Melton (1947) and found lacking.

(5) Compensatory, single-dimension pursuit. In the Miles (1921) Pursuit Test the task required of the subject is to compensate for changes in an electrical circuit, observed by the subject as movements of a needle, by moving the slide of a rheostat either to the right or left in order to keep the needle in line with a mark on a screen. The amount of deviation from the zero-point is integrated by wattmeters in arbitrary units. A recent modification of Miles' technique which is stated to be simpler and more dependable is the SAM Single-Dimension Pursuitmeter, reported by Melton (1947).

(6) Compensatory, multiple-dimension pursuit. The SAM Artificial Horizon Pursuit Test (Melton 1947) provides an example of a compensatory task requiring movements up and down as well as to the right or left. To perform this task the subject must rotate and simultaneously move in and out a single control-wheel, in such a way as to keep an 'indicator bar', drifting up and down and rotating about its center, in line with two fixed marks. In the SAM Multidimensional Pursuit Test a third dimension of movement is added. A panel viewed by the subject contains three instrument dials, the pointers of which are movable by means of two controls - a 'stick' and a 'throttle'. The stick is displacable in the two plane dimensions, controlling two of the dials; the throttle, which is moved forward and backward, controls the third. The subject manipulates the controls in such a manner as to maintain the needles at their zero points. A comparable multidimensional apparatus with a different display is reported by Stevens (1941).

A further complication of possible theoretical interest is a Pursuit-Steadiness Test developed by Farmer and Chambers (1929). In this test the subject is required to hold a stylus, with a ball on the end, inside a small metal cup which is moved irregularly in

speed and direction. Scores are determined by the duration of contacts of the stylus with the sides and bottom of the cup. A type of non-compensatory pursuit test differing from any described above adds the factor of physical work by utilizing a control lever which can be weighted from 2 to 40 pounds. A brief account of this test is given in Mackworth (1945, 1948). For a further discussion of apparatus and details of administration of pursuit tests, reference is made to Seashore (1928) and Melton (1947).

Since no marked functional differences are apparent in the results obtained with the several types of pursuitmeter (see Table 12), it seems justifiable to group them together for purposes of present consideration. Investigations of altitude consistently show decrements in performance with all types of pursuit-tests (Grether and Smith 1942; Gagne and Smith 1943; Loucks 1944; Green 1947; McFarland 1932, 1938; Barach, Brookes et al 1943; Brooks 1945). Further, the pursuit test appears to be sensitive enough to detect effects of dietary and other conditions superimposed on altitude. (Green et al 1945; Brooks 1945). Performance under the condition of alcohol showed a decrement (Miles 1924; McFarland and Barach 1936). Two minor studies of sleep reduction report negative or indeterminate results (Laslett 1928; Husband 1935). Noise yielded no performance deficit as measured by a test of the present type (Stevens 1941). Other findings obtained under miscellaneous conditions are reported in Table 12.

Intratest reliability coefficients for the Koerth pursuit rotor are given as high (.92, corrected) by Seashore, Buxton and McCollom (1940), and by Melton (1947), for the SAM modification, (.93 - .96, corrected). The immediate test-retest reliability coefficient is given as .88. In the same report the intratest value for the Miles compensatory pursuitmeter test is given as .74 (corrected, .90); the fact that calibration of this apparatus proves difficult may mean that the intertest values would be considerably lower. On the SAM modification of Miles' test similar intratest values were found: .73 - .85 (uncorrected), and .84 - .92 (corrected). Test-retest reliability values obtained under deficit-producing conditions showed considerable loss in the consistency of measurement: at ground level, .75, but at altitude, .19. These results on loss of test-retest reliability were confirmed by Green (1947). For the Artificial Horizon Test, a two-dimension pursuit task, values of .95 - .97 (intratest, corrected) and .85 (test-retest, trials 2 and 3) are reported. Reliability of a rate pursuit test (SAM Rate Control Test) is stated to be relatively low (Melton 1947). Insufficient use of compensatory and non-compensatory pursuit tests under the same conditions of testing precludes any statement of comparison of their reliabilities. Investigators are in agreement that pursuit tests are influenced by practice effects.

The relatively small amount of intercorrelational data, coupled with the wide variety of pursuit tasks employed, precludes any final statement about the generic characteristics of the tests. However, it does appear that all compensatory pursuit tests show the same pattern of intercorrelation with other tests. The SAM Single-Dimension Pursuit Test, the Artificial Horizon Test, the Stevens Coordinated Serial Pursuit Test and the Multidimensional Pursuit Test all correlate with other types of tests as follows: moderately high with the SAM Complex Coordination Test, Two-Hand Coordination Test and the SAM Rotary Pursuit Test; lower with Discrimination Reaction Time; and practically not at all with tests of finger dexterity and steadiness-aiming (Melton 1947). The rotary pursuit test correlates moderately high with Complex Coordination and Two-hand Coordination, but also correlates, to a greater extent than those listed immediately above, with finger dexterity and steadiness-aiming. Thus, relatively high correlations among the several types of pursuit tests have been demonstrated. Pursuit tests appear to be relatively heavily loaded with a single factor, which Melton names 'coordination', since it also appears in such tests as Complex Coordination. Data presented by Seashore (1940) suggest low correlations between the rotary type pursuit test and the simpler motor functions of reaction time and tapping. It is also significant that tests of the present type show little relationship with paper and pencil tests in general. Pursuit tests have further been shown to have appreciable validity for the prediction of pilot success (Melton 1947).

11. Discrimination Reaction-Time Tests

In the simple reaction time test, previously considered, a single response is made to a single stimulus. The discrimination reaction time test is more complex in that one of two or more responses must be made, in correspondence with two or more dissimilar stimuli. The chief dimensions along which such tests may vary are with respect to kind, number and complexity of both stimulus and response, as well as with respect to the relationships of the several stimuli to each other (Woodworth 1938). Differences in sensory modality, in quality, quantity, form and position of the stimuli occur within the variety of tests employed for measuring discrimination reaction time. Within any given test of visual discrimination reaction, the most commonly used type, the differential character of the several stimuli may be based on color, intensity, form or position, or on combinations of these. Responses likewise differ from test to test, and may be simple or complex, or may involve different reaction systems, as the hand, feet, or the entire body. Within a given test, the response may involve different movements of the same member, relatively similar movements of different members, or releasing movement to one stimulus and withholding it to others. Further, response may be discrete or serial. Lack of standardization in many of these respects, all but

Table 10

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Non-compensatory uniform pursuit 1. Pursuit Pendulum			
Miles	1924	Alcohol	8	(-)	3.2% over entire period.
Muscio Vernon	1922 1926	Repetitive work on task itself	1 1		Analysis of decrement due to fatigue.
Laslett	1928	Sleep reduction	4	(o)(?)	
		2. Rotary pursuit (Pursuit rotor)			
Husband	1935	Interrupted sleep	1	(o)	
Forbes, Dill et al	1937	Carbon monoxide	8	(o)	Up to 30% saturation.
Stevens	1941	Noise (90 and 115 db.)	4	(o)	
Consolazio et al	1947	Excess CO_2, decrease O_2 in sealed chamber - Heat	4-77	(-)	Chief decrement in untrained subjects. Practice curves differ from normal.
Seashore, Buxton and McCollom	1940	Normal	50		r(split-half) = .92 (corrected)
Melton	1947	Normal	N=300		r(intratest)= .93 - .96 (corrected)
			N=398		r(test-retest)= .88 (immediate)
		With divided attention		(-)	More difficult but not essentially different task.
		Varied speed of target		(-)	Decrement in scores as rate increased.

Table 10 (con.)

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Spence, Buxton and Melton	1945	Normal			Effects of practice, rest periods, intercorrelations with other tests.
Ammons	1947	"			
Nance	1947	"			
Seashore, Buxton and McCollom	1940	"			
B. Non-Compensatory - variable - direct pursuit.					
1. Eye-Hand Coordination (Farmer-Chambers) Pursuitmeter.					
Farmer and Chambers (and later articles)	1926	% accident rate	Industrial workers		Useful in accident-prone battery.
2. Modified Miles Pursuitmeter.					
McFarland	1932	Altitude	14	(-)	
McFarland and Barach	1936	Oxygen and alcohol	23	(-)	
McFarland	1938	Altitude	30 normal 35 psychoneurotics	(-)	Greater in psychoneurotics.
3. "Drive - Mobile".					
Barach, Brookes et al	1943 a	Altitude -15,000 ft.	16	(-)	
4. Two-Hand Coordination Test.					
Farmer, Chambers and Kirk	1933	% accident rate	Air crew apprentices and other workers		Valuable test for accident-prone and for selection of workers.

Table 10 (con.)

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Melton	1947	Normal	N = 2000 N = 700		r(intratest)= .80 - .91 r(test-retest)= .87 (28 days)
		Smoothness of control	N = 2000		No correlation with test performance.
		"Over-activity"	N = 600		No correlation with test performance.
		Air interruption -frequent and unpredictable	N = 800	(-)	
		Target size	N = 181		Smaller target, poorer scores.
Melton	1947	Normal			Summary of data on practice, test intercorrelations, and validity for classification.
		5. "Targetmeter" (Hoagland-Werthessen).			
Pincus and Hoagland	1943	Fatigue on apparatus itself	3	(-)	
	1944	Fatigue plus pregnenalone	14	(-) (+)	Pregnenalone improved fatigued performance.
Graham - Bryce et al	1945	"	6	(-)	With fatigue but no improvement with endocrine drug.
Melton	1947	Normal	1036		r(intratest)= .96 (corrected)

Table 10 (con.)

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		C. Compensatory Pursuit Tests. 1. Single-dimensional			
Miles	1924	Alcohol	8	(-)	
Laslett	1928	Sleep reduction	5	(?)	
Grether and Smith[1]	1942	Altitude - 18,000 ft. 15 min.	24	(-)	
Gagne and Smith[1]	1943	"	26	(-)	
Loucks[1]	1944	18,000 ft. - 15 min.	46	(-)	r(test-retest)= .75 - ground r(test-retest)= .19 - altitude.
		15,000 ft.	52	(-)	
Campbell (Loucks)[1] P.A.	1944	18,000 ft.	14	(-)	
		18,000 ft. + Sulfadiazine	17	(-)	Decrement with altitude unchanged by drug.
Melton	1947	Pressure-breathing 46,500	25	(-)	Decrement with pressure-equipment at ground as well as at altitude.
Green et al	1945	Altitude and diet (17,000 ft.)	50	(-)	Decrement greater with protein diet.
Green	1947	Altitude (17,000 ft.)	50	(-)	Analysis of individual variations at altitude.
Cogswell et al	1946	Diet-Vit. B restricted - 5 weeks	7	(o)	
Berryman et al	1947	Diet-Vit. B restricted - 15 weeks	7	(-)(?)	Some decrement followed by improvement on supplementation

1 Data summarized in Melton (1947).

Table 10 (con.)

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Melton	1947	Normal	N = 1500		r(intratest)= .84 - .92 (corrected)
		2. Two-dimensional Pursuit (Artificial Horizon)			
Loucks[1]	1944	Altitude (18,000 ft.)	45	(-)	Not so great as single-dimensional.
Melton	1947	Normal	N = 765		r(intratest)= .95 (corrected).
		3. Multidimensional Pursuit Tests			
Stevens	1941	Noise (90 & 115 db.)	5	(o)	
Loucks[1]	1944	Altitude (18,000 ft.)	(Not stated)	(-)	Least consistent decrement of pursuitmeters tested.
Cogswell et al	1946	Diet - Vit. B restricted - 5 weeks	7	(o)	
Berryman et al	1947	Diet - Vit. B restricted - 15 weeks	7	(-)(?)	Improvement with supplementation.
		D. Pursuitmeters not identified.			
Roughton et al	1941	Sulfonamide drugs	5	(o)	
Barmack	1939	2 hr. repetitive work on apparatus	10	(-)	
	1940	Same with benzedrine		(+)	Decrement retarded by benzedrine.
Brooks, M.	1945	Altitude and methylene blue (18,000-20,000 ft.)	3	(-)	Altitude impairment improved with drug.

[1] Data summarized in Melton (1947).

Table 10 (con.)

PURSUIT TESTS, COMPENSATORY AND NON-COMPENSATORY

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		E. Steadiness Pursuit Test.			
Farmer and Chambers Farmer, Chambers and Kirk	1929 1933	% Accident rate	200-1800		Not so useful as other tests in battery.
		F. Weighted Pursuitmeter.			
Mackworth	1945	Heat & Humidity	10	(-)	Critical temperature = 87.5°F (E.T.)
		50 lb. load		(-)	With greater load.
Carpenter	1946	Various handle loads - 10, 20, 30 and 40 lbs.	5	(-)	Increased amount of errors with 30 and 40 lb. loads. Also marked practice effects and machine variations.
Carpenter	1947a	Loads		(-)	With greater loads.
		High temperatures air-movement	12	(-)	At 87.5°F (E.T.) and above.
Carpenter	1947c	Air movement at high temperature	9	(-)	With temperature of 87.5°F (E.T.) and above.
				(+)(?)	Air movement has less effect than temperature.
Mackworth	1948a	Heat and Humidity	10	(-)	Critical temperature for scoring accuracy is 87.5° F.

precludes comparison of results obtained with different tests. Representative techniques for the measurement of discrimination reaction time are as follows:

Visual choice reaction requiring response (pressing a key) to a green light and withholding of response to a red light has been employed by Lee and Kleitman (1923), among others, as noted in Table 11. In a more complex form of what appears to be basically the same test, the subject must respond to only one of five lights, inhibiting response to any one of the remaining four when it is flashed (Tuttle, Wilson and Daum 1949).

A second type of discrimination reaction test differs from the choice reaction, described immediately above, in that response is not withheld to any stimulus, but, on any given trial, one of several possible responses is made, depending on which stimulus appears. Thus Hollingworth (1912) has made use of a test in which the subject responds with the right hand to a red light which appears on one side of a panel, and with the left hand to a blue signal which always appears on the other side. Tests of this general type may be further distinguished depending on whether response must be based on both position and color, as in Hollingworth's test, or on color alone. In the former case, a light of given color appears invariably in the same position; in the latter, lights of any given color appear in any of the several positions on different trials (or lights may appear in the same single position on different trials.) No technique of the latter sort was noted, although its relation to other types of discrimination-reaction remains a problem of possible systematic importance. A purely positional type in which the cues made use of are of identical color but are presented in two different positions, has been employed by Seashore, Starman et al (1941). In this situation the subject lifts the appropriate hand, right or left, from either of two telegraph keys, depending on which one of two red lights, on the right or left, is presented.

The color-positional response has been complicated by the addition of more stimuli and response possibilities in the Sillitoe (1921) apparatus employed by McFarland (1932 and series). The subject must respond by pressing a key corresponding to the lighted member of five differently colored lights. A variation, involving response of the entire body, of this type of discrimination is reported by Keys and his associates (1945 and series).

A third type of discrimination reaction test involves response to visual stimulus patterns differing from one another with respect to the spatial arrangements of their component parts, some of which are common to several presentations. The SAM Discrimination Reaction Test (Melton 1947) requires that the subject react by pushing one of four toggle switches in response to the simultaneous lighting of a red and a green signal lamp. The position of the red light with respect to the green rather than the onset of a particular light, determines which of the four switches is the correct one. The subject

is instructed in the technique of correct response, although it has been suggested that a test requiring the subject to determine the correct response for himself would be interesting. In the standard SAM test, time required to operate the correct switch on each of a series of trials is accumulated on an electric time clock to yield the score.

A mixed form of discrimination reaction test involving various techniques has been reported by Farmer and Chambers (1926). Variations tried out with the apparatus involve use of different sensory modalities, varying numbers of stimuli (2 - 6), varying positions of keys to which response must be made, prescribing response only when presentation is preceded or followed by another stimulus, basing responses on coded patterns and a number of others. In its final form, this test was retained as a choice reaction to six stimuli involving different sensory modalities.

Another type of discrimination reaction in which both stimulus and response are highly complex is the SAM Complex Coordination Test (Melton 1947). This test was developed to measure the ability of individuals to make control movements of an aeroplane type stick and rudder in response to successively presented combinations of visual signals. The subject is presented with three double rows of lights, one row of each pair being red, and the other green. A pattern of three red lights, one in each of three rows, calls for a coordinated response (or successive responses) of hand and foot to light the corresponding green lights in the response row. After the match has been obtained and held for a brief period, a new pattern of lights is presented for another response. Score is either the number of patterns matched correctly in a fixed time or time required to complete a fixed number of patterns. A large number of variations have been introduced into the conditions of this test, at least some of which carry it beyond the scope of discrimination reaction.

A further important distinction among discrimination reaction tests may be made in terms of their discrete or serial character. In the Seashore Discrimeter (Seashore 1928) the rate of response of the subject determines the rate of presentation of the subsequent stimuli. The subject is presented with one of four stimuli seen through an aperture. When the appropriate one of a bank of four keys is pressed, a tachistoscope is actuated, producing the next stimulus. Score is total time required to respond to a given number of signals. The Psychergometer of Bills (1936) appears to be based on a similar principle, but with the important difference that the aspect of performance selected for scoring is number and length of errors and 'blocks' rather than time.

A variant form of discrimination-reaction test, which differs from those just described in two presumably important respects, is that of Dockeray (1922). The subject is presented with one of five

lights of different intensity, and is required to press a key corresponding to it. Since only one light is present at any given moment, discrimination must be made on the basis of absolute cues. Secondly, the discrimination of stimuli, differing only in degree of intensity, and similar in all other respects, probably makes the discrimination more difficult than in other tests considered.

Results obtained with all types of discrimination-reaction tests are arrayed in Table 11. The findings support the statement that this type of test is sensitive to altitude and allied conditions at approximately 15,000 feet and above (McFarland 1932, 1937-I, 1937-II, 1938; McFarland and Dill 1938; Wespi 1933, 1936; Bills 1937; Bagby 1921). The findings of Gagne and Smith (1943) need not be interpreted as inconsistent with this generalization in view of the relatively short exposure (15 minutes) at 18,000 feet. Rahn, Otis et al (1946) report decrement in response to acapnia induced with a pneumolator at 30,000 feet, and McFarland (1938) has reported less impairment at altitude when 3% CO_2 is added. Increased atmospheric pressure is reported by Shilling and Willgrube (1937) to impair discrimination reaction time performance. A majority of studies of fatigue and related conditions (Lee and Kleitman 1923; Cooperman, Mullin and Kleitman 1934; Patrick and Gilbert 1896; Husband 1935) agree in reporting negative results. Bills (1937) and Tyler (1947), however, report decrement with more protracted conditions of testing. Noise and vibration showed no clear cut effects (Dockeray 1922; Baker 1937; Stevens 1941; Lewis 1943), although Taylor (1935) has demonstrated some depressive influence of 'startle' produced by loud noises. Under the condition of stress induced by air interruption, Melton (1947) has reported a deficit on the Complex Coordination Test. Keeton et al (1946) and Mitchell et al (1946) report decrement resulting from cold. Results on effects of diet and drugs are also summarized in the table.

Reliabilities reported for discrimination-reaction time differ for the several types of test. For a choice discrimination-reaction, Sisk (1926) has calculated a reliability of .64. Seashore, Starman et al (1941) give a range of coefficients from .83 to .89 for a visual positional discrimination reaction test. The intratest reliability of the SAM Discrimination Reaction Test has been determined to vary from .87 - .93 (corrected), and the test-retest value, as .78 (Melton 1947). The same investigator gives a coefficient of .89 (intratest, corrected) and .87 (test-retest) for the Complex Coordination Test. A number of alterations introduced into the test conditions, such as adding an additional task (materials to be memorized), reduced the consistency of measurement of the test (r's range from .60 - .79). If the reliability value of .95 (intratest corrected) given for a serial discrimination reaction time test by Melton (1947) may be assumed to be typical, it is important to note the gain represented in the self-paced type of test over the apparatus-paced type. In support of this point,

is the high intratest reliability, .93 (corrected), offered by Seashore for the Discrimeter (Seashore, Buxton and McCollom 1940). Farmer and Chambers (1926) report sufficiently high intercorrelations between various types of complex reaction time tests to justify substituting a standard choice reaction for other more complex variations.

The psychological functions underlying performance on these tests is elucidated only by fragments of intercorrelational evidence. Sisk (1926) has given the interrelationship between simple visual and choice reaction times as .67. Lanier (1934), using two highly similar tests reports a perfect correlation between a choice and a color-positional discrimination reaction test. The SAM Discrimination Reaction Test is stated by Melton to have a low (.23 - .43) intercorrelation with the Complex Coordination Test. The SAM Discrimination Reaction Test is correlated with the serial form of the same test (SAM Self-pacing Discrimination Reaction Test) to the extent of .58.

Sisk (1926) reports a simple visual choice to correlate with cancellation to the extent of .13, with 'making lines', .30, and with simple reaction, .67. Performance on the Seashore discrimination reaction test is reported to have a .06 correlation with steadiness (Seashore 1940). Melton (1947) finds positive intercorrelations between the Discrimination Reaction Test and the SAM Two Hand Coordination Test, and a finger dexterity test. The Complex Coordination Test is reported by the same source to be related with other tests as follows: with SAM Rotary Pursuit, .34 - .41; with a finger dexterity test, .22 - .35; and with a steadiness test, .12.

It may be significant that the SAM Discrimination Reaction Test has considerable validity for the prediction of all three types of aircraft personnel (pilots, navigators and bombardiers). Factorial analysis of this test shows it to be heavily loaded with a function measured by a number of paper and pencil tests, and to be high in a 'psychomotor precision' factor. The Complex Coordination test appears to be heavily loaded with a 'coordination' and a 'perceptual' factor. As Melton suggests: "Future research designed to determine why this test has such ubiquitous validity should lead to a better understanding of the psychological functions which must be measured in a test used for the selection of aircraft pilots." (Melton 1947, p. 176).

12. Naming Tests

Rapidity in naming colors or forms presented in rapid succession to the subject, although often classified as an association test, has clear affinities with descrimination reaction time considered in the preceding section. In tests of the present type the emphasis appears to fall less on the 'symbolic' aspect of the verbal response than it does on the purely motor side. On this assumption there

Table 11

DISCRIMINATION REACTION TIME TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Choice Reaction to one stimulus but not to another.			
Lee and Kleitman	1923	Sleep privation (114 hrs.)	1	(o)	
Cooperman, Mullin & Kleitman	1934	Sleep privation (60 hrs.)	6	(o)	
Fay	1936	Smoking	21	(?)	Individual variability.
Keeton et al Mitchell et al	1946 1946	Cold and diet	12	(-)	Decrement reported for cold. Ambiguous results on diet.
Tuttle, Wilson & Daum	1949	Diet and short fasts	5	(-)	On omission of breakfast.
		B. Visual discrimination (Color-positional) tests. **1. Discrimination between two stimuli.**			
Patrick & Gilbert	1896	Sleep privation (90 hrs.)	3	(o)	
Hollingworth	1912	Caffeine	16	(?)	
Hollingworth	1914	Diurnal change	15	(-) (+)	Some evidence for diurnal rhythm.
Slocombe & Brakeman	1930	% accident rate	86 motormen		Battery of tests correlating with accident-proneness.
Thornton, Holck & Smith	1939	Benzedrine Caffeine	3	(+)(?) (?)	Slight increment. Variable.

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Rahn, Otis et al	1946	Acapnia - 30,000 ft. - pneumolator	10	(-)	Progressive with changes in alveolar air composition.
Seashore, Starman et al	1941	Normal testing	47		r(intratest) = .83 - .89 uncorrected correlations with other reaction time tests.
		2. Discrimination between multiple stimuli.			
McFarland	1932	Anoxia (rebreathing)	11	(-)	
McFarland & Barach	1936	Oxygen & Alcohol	23	(-) (o)	Decrement in alcohol. No difference between air and O_2 after ingestion of alcohol.
McFarland	1937-I	Altitude (rapid ascent) 14,890 ft.	6	(-)	Also greater variability.
	1937-II	Altitude (acclimatization)	10	(-)	17,500 ft. and above.
	1937-II	Natives at altitude and sea level	70 workmen	(-)	Altitude group slower and more variable.
McFarland	1938	Altitude (rapid ascents)	200	(o) (-)	Below 14,000 ft. Above 14,000 ft.
McFarland & Barach	1937	Altitude	25 normal 32 psychoneurotics.	(-)	Greater impairment in psychoneurotics.

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
McFarland & Dill	1938	Comparative altitudes	3 & 10	(-)	Less decrement at 17,500 on mountain expedition than in chambers at 17,000 ft. for 4-6 hrs.
	1938	Altitude + 3% CO_2	4	(+)	3% CO_2 improved performance at 17,000 ft.
Scott, W. S.	1940	Normal	children		Analysis of learning task.
Melton	1947	Normal			r = .75
		3. Gross body reaction.			
Keys et al	1944 b	Diet - Vit. B deficient - 40 days	8	(o)	
Keys et al	1945	Diet - Vit. B deficient - 161 days	8	(o)	
Brozek et al	1946	Acute deprivation (23 days)	8	(-)	
Taylor et al	1945	Fasting	4	(-)	
Franklin & Brozek	1947	Distribution of practice	36		Data on practice curves.
		C. Visual relational discrimination tests. (SAM Visual discrimination Reaction Time Test)			
Gagne & Smith	1943	Altitude - 18,000 ft. (15 min.)	13	(o)	
Melton	1947	Normal testing	AAF candidates		r(intratest) = .87 - .93 corrected r(test-retest) = .78

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
D. Visual discrimination or choice reaction tests not identified.					
Wespi	1935 1936	Altitude 12,000 ft. 16,000 ft. 23,000 ft.	12	(o) (?) (-)	Decrement at higher altitudes.
Cheney	1936	Caffeine Coffee	5	(+) (+)	8% 4%
Horvath & Freedman	1947	Cold (-22°F) 8-14 days	22	(o)	
Glickman et al	1946	Cold and diet	12	(?)	
Tyler	1947	Sleep privation (24 - 112 hrs.)	291	(o) (-)	No change - 2 min. test. Decrement - 10 min. test - beginning 60 hr.
		Benzedrine		(+)	Prevents decrement (p value = about 5% level)
		Barbiturates		(o)	
Varé	1932	Alcohol	100	(-)	
Shilling & Willgrube	1937	Increased atmospheric pressure	46	(-)	
Tufts College	1942	Sleep privation (50 hrs.) Protracted alertness		(-)	

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		E. Choice Reaction to various sensory modalities (visual, auditory, tactual).			
Farmer & Chambers " " Farmer, Chambers & Kirk Farmer & Chambers " "	1926 1929 1933 1936 1939	% accident rate in industrial workers and drivers	Large groups of industrial workers and drivers		Part of battery useful in distinguishing accident-prone.
Slocombe & Brakeman	1930	% accident rate	86 motormen		Found test (6 stimuli) too unreliable for usefulness.
		F. SAM Complex Coordination test.			
Melton	1947	Air interruption at frequent, unpredictable intervals.	N= 800	(-)	
		"Hand pressure" "Grip tension"	AAF candidates		No correlation between these indices of "tension" and performance.
Lewis	1943	Noise and vibration	80	(o)	
Nance, Buxton & Spence	1944	Distraction lights	100	(o)	
Melton	1947	Normal testing	N= 2000 N= 1800		r(odd-even)= .80 - .91 r(test-retest) = .78 - .87

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Mashburn	1934 a	Normal testing			Contain data on performance under normal testing conditions, reliabilities, validity for classification and selection, effects of practice, and inter-correlations with other tests.
"	1934 b	" "			
Glenn	1935	" "			
McFarland & Franzen	1943	" "			
Spence, Buxton & Melton	1945	" "			
Buxton & Spence	1946	" "			
McFarland & Channell	1947	" "			
Melton[1]	1947	" "			
Nance	1947	" "			
		G. Visual Discrimination reaction to light intensities.			
Dockeray, F.	1922	Distraction Fatigue	(few)	(?)	
Fisher, V. E.	1927	Smoking	4	(?)	
Dorcus & Weigand	1929	Carbon monoxide	5	(o)	
Taylor	1935	"Startle"	45	(-)	
Baker	1937	Distraction (noise)	9	(?)	
		H. Self-paced serial.			
Bagby	1921	Anoxia (rebreathing)	pilots	(o)(-)	No decrement until final stages.
Bills	1937	Anoxia (10.5%) Fatigue - 1 hr. repetitive work on apparatus	10	(-)	Equivalent to decrement caused by 1 hr. work on task.

[1]Summarizes all the data on this test.

Table 11 (con.)

DISCRIMINATION REACTION TIME TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Husband	1935	Interrupted sleep	1	(o)	
Stevens	1941	Noise	5	(o)	
Seashore, Burton & McCollom	1940	Normal	50		r(split-half)=.93 corrected
Campbell, M.	1934	Normal	50		r(intratest) = .96 - .98 corrected
Farnsworth, Seashore & Tinker	1927	Normal			Data on reliabilities, intercorrelations, group factors, lack of validity for selection of aircrew.
Seashore, Burton & McCollom	1940	Normal			
Campbell, M.	1936	Normal			
Melton	1947	Normal			

appears to be little essential difference between the two tests of Bills, for example, which are in virtually all respects identical except that in the color-naming test response is made to a voice key, and in the Psychergometer, to a manually operated key. What may serve to differentiate the form and color-naming tests from complex reaction times is the aspect of behavior selected for scoring; errors and 'blocks', which are usually not exploited by reaction time tests, are given more weight than time of reaction in the tests presently under consideration.

In a standard form of the color-naming test, colored stimuli are presented in rapid succession to the subject one at a time through a small aperture. The subject responds by speaking the names of the colors into a voice-key. Results obtained with a revision of the older color-naming test in which manual response keys are substituted for voice-keys, appear to parallel closely those taken with the original verbal response form (Bills 1936 and series). The forbear of both of these tests is the Woodworth-Wells (1911) color-naming test which involves the use of a card containing 100 colored squares - yellow, blue, black, red and green, arranged in ten rows and ten columns, in random order. The subject is instructed to name the colors as rapidly as possible, and the total time in seconds and errors are recorded. This older form of the test, although it appears to offer less possibility of control than that of Bills has been more widely used in studies of deficit.

Impairment in performance on color-naming tests under conditions of altitude is reported both in terms of response-latencies and errors (blocks) by Bills (1937) and by McFarland (1937-I, 1938). These data suggest that number and duration of blocks is a more sensitive index of the present type performance than response time alone. Increased blocking has also been shown by Lee and Kleitman (1920) and by Warren and Clark (1937) to result from sleep privation, but a third study of this factor (Cooperman, Mullin and Kleitman 1934) yielded no deficit. Alcohol, according to the studies of Hollingworth (1923-24), impairs performance, while caffeine facilitates it over the normal level (1912). Results obtained under other conditions are included in Table 12.

That high reliability estimates for color-and form-naming have been obtained may be inferred from the work of Lanier (1934). Intercorrelation between color-naming and form-naming is reported by Garrett and Schneck to have a value of .73. Lanier (1934), using speed as a measure of response has demonstrated a fairly high average intercorrelation (.57) to obtain between two tests of form-naming and two of color-naming. The same worker gives intercorrelations between form- and color-naming and other tests as follows: simple reaction time, -.35 to - .45; simple discrimination reaction time, -.38 to -.49; cancellation, .20, substitution, .42, simple card sorting, .16, and complex card sorting, .67.

Table 12

NAMING TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Remarks
		A. Color and Form naming.			
Hollingworth	1912	Caffeine	16	(+)	
Hollingworth	1914	Diurnal variation	15	(+) (-)	Some evidence of diurnal rhythm.
Lee and Kleitman	1923	Sleep privation (up to 114 hrs.)	1	(o) (-)	Increased number of errors in a long series (1200).
Hollingworth	1923-24	Alcohol	6	(-)	
Eagleson	1927	Monthly periodicity	4 women	(o)	
Glaze	1928	Fasting (10-33 days)	3	(o) (-)(?)	Short fasts. Long fasts. Practice uncontrolled.
Jersild and Thomas	1931	Adrenaline	6	(?)	
Cooperman, Mullin and Kleitman	1934	Sleep privation (60 hrs.)	6	(o)	
Ryan and Warner	1936	Driving (8-1/2 hrs.)	6	(?)(-)	Tendency to decrement.
Bills	1931	Experimental fatigue	Series of experiments		Relation of number and length of blocks to fatigue.
"	1935	" "			
"	1936[1]	" "			
"	1943	" "	"		
Bills	1937[1]	Fatigue and anoxia	10	(-) (-)	Performance in 10% O_2. Compares with that following 1 hrs. work on task itself.

[1] Used Psychergometer (See Discrimination Reaction Time) for presentation of stimuli.

Table 12 (con.)

NAMING TESTS

Source	Year	Condition	Subjects	Code	Results: Remarks
Warren and Clark	1937	Sleep privation (65 hrs.)	4 exper. 4 control	(-)	Decrement expressed in number and % blocks.
McFarland	1937 I	Altitude (rapid ascents)	6	(o) (-)	No decrement in time till 20,000 ft. More errors at 15,000 ft.
	1937 II	Altitude (acclimatization)	10	(o) (-)	Same as above.
McFarland	1938	Altitude	200	(o) (-)	Decrement in time and errors is related to rapidity of ascent and height. Errors more sensitive index than time.
		Altitude + 3% CO_2	4	(+)	Improved altitude performance.
		Altitude	30 normal 35 psychoneurotics	(-)	Greater in psychoneurotics.
		Trans-Pacific flights (9,000 - 12,000 ft.)	12	(?)	
Berdie	1940	Benzedrine	15	(o)	
Roughton et al	1941	Sulfanilamide	3 exper. 2 control	(o)	

Table 12 (con.)

NAMING TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		B. Naming letters.			
Patrick and Gilbert	1896	Sleep privation (90 hrs.)	3	(?)(o)	
Robinson and Herrmann	1922	Sleep privation (60-65 hrs.)	3	(o)	
Kleitman	1923	Sleep privation (40 - 115 hrs.)	6	(o)	
Glaze	1928	Fasting (10-33 days)	3	(-)	General decrement.
		C. Visual Work test.			
Brozek, Simonson and Keys	1947	Fatigue - repetitive work on task itself		(-)	Also greater variability.
Simonson, Brozek and Keys	1948	Diet and fatigue	6	(-)	Differential dietary effects.

13. Card-Sorting Tests

These tests have in common the requirement that the subject indicate discrimination between a series of cards of different kinds by placing them in a number of designated positions. The nature of the cards to be sorted differs from test to test, some utilizing playing cards, and others picture cards of various sorts. Likewise the number of categories into which the cards are to be sorted varies widely, in the tests cited, from 4-30. Discrimination is commonly based on visual cues; however, in some tests the subject must distinguish between the cards tactually, on the basis of holes of different patterns punched in the cards. Probably most significant among the variables in tests of the present sort are differences in instruction given to the subject, for, depending on these, as well as on the indices of performance selected for measurement, this test may become one of reversal of set, of learning, or of other functions presumably not sampled predominantly by the standard card sorting test. Scores may be derived from time consumed in completing the task, from errors and blocks, or combinations of these.

Examination of results arrayed in Table 13 shows that altitude is the only condition investigated with tests of the present type which reveals a decrement, and then only at extreme altitudes (West et al 1944; Gerstell 1946; Hoffman et al 1946). Bagby (1921), using a rebreathing apparatus, and Lowson (1923) failed to obtain significant decrement at lower altitudes. No deficit in performance is reported for such varied conditions as 'fatigue' (Johnson 1922) (Husband 1935), smoking (Carver 1922) and noise (Stevens 1941).

Card sorting, according to findings summarized by Garrett and Schneck (1933) has a reliability range of .72 - .98, depending on the characteristics of the tests. It is noteworthy that the several versions of the test analyzed by Tinker et al (1932) all proved to be highly reliable. It has further been demonstrated that variability of response, speed of performance, and progressive learning are all influenced by changes in motor sequences and in complexity of the discrimination required of the subject. Card sorting tests are, according to general agreement, highly influenced by practice.

On intuitive grounds card sorting tests are stated to measure speed of discrimination and reaction. According to evidence presented by Garrett and Schneck card sorting correlates low both with tests of physical capacity, at one extreme of performance, and with those of general intelligence, at the other.

Table 13

CARD SORTING TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Johnson, B. J.	1922	"Fatigue"	children	(?)	
Carver	1922	Smoking		(?)(o)	
Bagby	1921	Anoxia (rebreathing)	pilots	(o)	
Lowson	1923	Altitude	5	(?)	
Pollock and Bartlett	1932	Noise		(o)	Slight deficit which quickly disappeared.
Kleitman	1933	Diurnal variations	6	(-) (+)	Evidence of diurnal rhythm.
Husband	1935	Interrupted sleep for 1 month	1	(o)	
Stevens, S. S.	1941	Noise (90 & 115 db.)	5	(o)	
West et al	1944	Altitude (high)	Navy pilots	(-)	These 3 studies are concerned with the test as "indoctrination" for altitude and as an "index" of useful consciousness.
Gerstell	1946	Altitude (high)	"	(-)	
Hoffman et al	1945-46	Altitude (28,000 - 38,000 ft.)		(-)	
Tinker, Imm et al	1932	Normal	45		Highly reliable. r(intratest) = .90 to .98.

14. Cancellation Tests

Cancellation tests have the common requirement that the subject examine a series of stimuli (words, numbers or geometric forms) indicating, with maximum speed and accuracy, certain designated items as they recur. A time limit is usually set on the task and the score taken in terms of number of items cancelled during the time limit, with or without reference to errors.

Variations among cancellation tests involve such factors as: number and distribution of elements to be cancelled, degree of meaningfulness of material, duration of test, and, principally, the nature of the instruction given to the subject, whether simple or complex. For an account of standard cancellation procedures the reader is referred to Garrett and Schneck (1933). Recent improvements in the construction of tests of the present type have emphasized uniform stimulus elements, equal availability of items to be cancelled, and increased control of the degree of meaningfulness of the material (Finan 1942; Weston 1945).

Results obtained with cancellation tests under a variety of conditions are summarized in Table 14. Of two investigations of anoxic effects listed, both show a decrement in performance (Gellhorn 1937; Gellhorn and Joslyn 1937). Of two studies of the effects of noise, one yielded positive (Burris-Meyers et al 1942) and the other less determinate results (Obata et al 1934). With the exception of a deficit in calcellation performance under the conditions of dietary deficiency (Guetzkow et al 1946) the remaining results obtained under conditions listed in Table 14 are either uninterpretable or negative.

Reliabilities, which may be assumed to differ, depending on the type of test, have been reported for the Woodworth-Wells versions of number and letter cancellation as .76 and .80, respectively (Garrett and Schneck 1933). Whipple (1914) states that reliability coefficients range from .60 - .97 for various forms and lengths of the test. In a more recent study Travis (1947), using the Whipple letter cancellation test, obtained a reliability coefficient of .86 (trials 1 and 2). Effects of practice on the test have been noted by a number of investigators.

The psychological functions sampled by the test have been variously labeled, on intuitive grounds, as 'attention', 'rate of perception' and 'discrimination'. It seems clear that although a minimum of motor skill is demanded by cancellation, the test is not primarily one of motor ability. Travis (1947), in the same study cited above, reports intercorrelations of the Whipple letter cancellation test with other tests as follows: with accomodation and convergence, .39; with motor speed as tested by a 'reach and turn' test, .44; with visual acuity as tested by the Snellen test chart, .19. Guilford (1947) on the basis of a factorial analysis

suggests loadings of a perceptual and verbal-intellectual sort. In line with such an interpretation, Garrett and Schneck (1933) point out that cancellation shows a "fair degree of correlation with those mental tests which demand quickness, such as analogies, completion and word building."

15. Substitution Tests (Code)

In code tests the common characteristic is the requirement that one set of characters be substituted for another set in accordance with prescribed instructions. A significant difference between the several types of substitution test appears to be the type of material substituted: whether letter for letter, digit for letter, digit for symbol, or other. Thus the Woodworth-Wells (1910-11) code substitution test, the forbear of such tests, requires that the subject respond by substituting digits for geometrical forms. The Johnson (Johnson and Paschal 1920) version, which has probably received widest use among tests of the present sort, requires the substitution of one letter for another. In this test, the top line on a printed page gives the alphabet, and a line immediately below it, the alphabetical code to be substituted in the materials below. The materials consist of five short lines to be transliterated. Twenty different forms of the test, presumably identical in degree of difficulty, are available for use. The subject is instructed to transliterate the 50 letters on the page as rapidly as possible. Scores may be based on time, or errors, or on both. Additional factors which differ from test to test are: degree of meaningfulness of material to be transliterated, number of units to be substituted, availability of key to the subject (whether initially only, or throughout the test). The last mentioned variable appears to be an especially important one, since it illustrates clearly how a difference in procedure, within otherwise similar tests, alters the nature of the psychological function involved; in the present case from a test heavily loaded with 'memory' to one in which that factor is minimized. Details of construction and administration of tests of the present type are given in Whipple (1914), in Garrett and Schneck (1933) and in Melton (1947).

Results arrayed in Table 15 show that substitution performance is impaired under conditions of altitude (Johnson and Paschal 1920; Lowson 1923; McFarland 1937-I; 1937-III; 1938; McFarland and Dill 1938; McFarland and Edwards 1937; Knehr 1940; Malmo and Finan 1944; Brooks 1945; Grether and Smith 1942; Gagne and Smith 1943). Some evidence indicates, too, that the test is sensitive to other conditions added to altitude as 3% carbon dioxide (McFarland 1938), methylene blue (Brooks 1945) and diet (Eckman et al 1945). However, McFarland (1938) has shown recovery in performance after an hour's stay at altitude, Malmo and Finan's (1944) data showed no impairment in amount of work, but only in errors, and Loucks' (1944) evidence

Table 14

CANCELLATION TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Hollingworth	1912	Cancelling A's	Caffeine	16		
Muscio	1920	Underlining numbers containing 3 specified digits	Diurnal Fatigue	34	(?)	Diurnal fluctuations in efficiency.
Muscio	1920	3 operations on 3 digits	Diurnal Fatigue	34	(?)	
Sowton & Myers	1928	"	Monthly periodicity	women	(o)	
Lee & Kleitman	1923	Cancellation	Sleep privation (112 hrs.)	1	(o)	
Hull	1924	Cancelling A's	Smoking	19	(o)	
Weiskotten	1925	Cancelling A's	Sleep privation (3 days)	1	(o)	
Whiting & English	1925	Cancellation	High speed work (90 min.)	4	(o)	
Fisher, V. E.	1927	Number work test (Hopkins)	Smoking	(small no.)	(o)	
Obata et al	1934	8 Japanese letters	Noise		(-)(?) (+)(?)	Small differences in output. Gain in accuracy.
Gellhorn	1937	Cancelling 4	Anoxia (rebreathing)	15	(-)	
Gellhorn & Joslyn	1937	Cancelling 4	Anoxia (rebreathing) (7 - 9% O_2)	(not given)	(-)	

Table 14 (con.)

CANCELLATION TESTS

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Hollingworth	1939	Woodworth-Wells number checking	Continuous work (8 hrs.)	6	(o)	Practice effects masked decrement at end of day.
Reynolds & Shaffer	1943	Numbers work test (Hopkins) 2 digits - 2 operations	Sulfonamide drugs	24 army 49 students	(o)	
Burris-Meyers et al	1942	Cancellation	Noise 110-120 db.	8	(-)	7 out of 8 subjects showed decrement in cancellation while counting.
Guetzkow et al	1946	Underlining 4's	Vit.-B complex deficiency (25 weeks)	8	(o) (-)	No change in rate of learning but difference of level of performance.
			latter part acute deprivation (22 days)		(-)	Decrement in acute stage.
Tyler	1947	(Not stated)	Wakefulness (24-112 hrs.)	(Not stated)	(?)(-)	Results not clearly stated.
			Benzedrine		(?)(+)	
			Barbiturates		(?)(-)	

indicates an unreliable decrement with a brief stay at altitude. Other decrements have been reported with alcohol (Hollingworth 1923-24; Miles 1924; McFarland and Barach 1936), sulfanilamide (Roughton et al 1941) and Vitamin B deficiency (Berryman et al 1947). Cold temperatures are reported by Horvath and Freedman (1947) to induce decrement due to loss of finger dexterity. Absence of impairment is reported for a number of conditions, including noise (Stevens 1941; Burris-Meyers et al 1942), which are summarized in the table.

Reliabilities are given by Garrett and Schneck (1933) for the Woodworth-Wells digit-symbol test as .70, and for another similar test as .78. Melton reports the test-retest reliability of the SAM Substitution Test to be .79 as determined on the ground, but only -.22 at altitude. This study (Melton 1947) concurs with other investigators in finding the code test somewhat susceptible to practice. In the same studies, however, it has been shown that the test employed was both stable and sensitive, with performance levelling off fairly rapidly.

Code-substitution has classically been called an 'association Test'. A number of studies have demonstrated a high degree of correlation between code substitution and intelligence tests. Garrett and Schneck (1933) call attention to the motor factor in highly practiced performance, when the test may become little more than one of speed of writing. Melton (1947) gives correlations of code-substitution with other tests as follows: with SAM Single Dimension Pursuit, .33; with SAM Steadiness Aiming, .06; with SAM Peg Moving Test, .08; and with an addition test, .08. Results appear to demonstrate consistently little relationship between substitution tests and those of simple motor function. McFarland (1938) considers that the Johnson test measures a fairly wide range of psychological functions including attention, accuracy, adjustments of accommodation and convergence, and writing.

16. Computation Tests

Computation tests require the solution of simple and complex problems in addition, subtraction, multiplication and division, singly and in combination. In some tests a pencil or other aids may be used in determining the solution, in others the problems must be solved 'mentally'. The Woodworth-Wells (1910-11) test, which has been widely used, requires the continuous 'mental' addition of 100 two-place numbers presented in four columns of 25 each. In a different form of the test the subject is instructed to add a constant amount to each of the two-place numbers. In a more complex form of mental computation Macht and Macht (1939) demanded the addition of a constant amount to a two-place number which is then multiplied by a second constant number; a third constant number must then be subtracted. A pencil and paper addition test requires the subject to add digits from left

Table 15

SUBSTITUTION TESTS (CODE)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Johnson, B.	1919	Letter-letter	Anoxia (rebreathing)	(6000)(?)	(-)	
Johnson & Paschal	1920	Letter-letter	Anoxia (rebreathing)	"	(-)	
Hollingworth	1923-24	Symbol-digit	Alcohol	6	(-)	
Johnson, B. J.	1922	Symbol-symbol	Fatigue	Children	(?)	
Lowson	1923	Symbol-digit	Altitude	5	(-)(?)	Decrement, but number of observations small.
Miles	1924	Letter-letter	Alcohol	8	(-)	
Laslett	1924	Letter-letter	Wakefulness (50 hrs.)	9	(?)	
Laird	1925	Starch substitution test	Diurnal and weekly changes	112	(+) (-)	Some evidence of diurnal and weekly rhythms.
Eagleson	1927	Symbol-letter	Monthly periodicity	4 women	(o)	
Laslett	1928	Letter-letter	Reduction in sleep -5 nights	4	(?)	but probably (-)
Dorcus and Weigand	1929	Letter-letter	Carbon monoxide	6	(o)	
Weiskotten and Ferguson	1930	Morse Code	Sleep privation (3 days)	5 exper. 2 control	(?)	
Jersild & Thomas	1931	Symbol-digit	Adrenaline	6	(o)	Trend in direction of decrement.
Kleitman	1933	Letter-letter	Diurnal variations	6	(+) (-)	Diurnal variation in both speed and accuracy.

Table 15 (con.)

SUBSTITUTION TESTS (CODE)

Source	Year	Test	Condition	Subjects	Code	Results: Remarks
Husband	1935		Interrupted sleep - 1 mo.	1	(o)	
Davis, R. C.	1936	Digit-letter	Aspirin	33	(o)	
Hinsie et al	1934	Digit-symbol	Oxygen administration	10 dementia praecox patients		Variability
McFarland & Barach	1936	Digit-symbol	Oxygen and alcohol	23	(-)	With alcohol. No difference with O_2.
McFarland & Barach	1937	Letter-letter	Altitude (10% O_2)	25 normal 32 psycho-neurotics	(-) (?)	Reliable decrement for psychoneurotics but not for normals. Increased variability.
McFarland	1937-I	Letter-letter	Altitude (15,000 ft.)	6	(-)	Decrement in 4 subjects.
McFarland	1937-III	Letter-letter	Altitude (17,500 ft.) (20,000 ft.)	10 (acclimatized)	(-)	Greater at 20,000 ft.
McFarland & Edwards	1937	Letter-letter	Flight (12,000) (variable)	27	(-)	Similar to test of 12,000 ft. in chambers.
McFarland	1938	Letter-letter	Altitude (rapid ascent -10,000 ft.)	200	(o)(-)	Impairment in first hour but not in second.
			(12,000 ft. and above)	30 normal 35 psycho-neurotics	(-) (-)	Decrement greater in psychoneurotics.
			Altitude + 3% CO_2	4	(+)	Improved performance.
			Actual flight conditions	12	(-)	

Table 15 (con.)

SUBSTITUTION TESTS (CODE)

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
McFarland & Dill	1938	Letter-letter	Comparison of altitude	10 3		In chambers (16,000 - 20,000 ft.) (4-6 hrs.) greater impairment than with prolonged acclimatization.
Knehr	1940	Letter-letter	Anoxia (rebreathing) benzedrine	8	(-) (o)	Altitude decrement not affected by benzedrine.
Stevens	1941	Letter-letter	Noise (90 & 115 db.)	5	(o)	
Roughton et al	1941	Letter-letter	Sulfanilamide	3 exper. 2 control	(-)	
	1942	Letter-letter	Sulfadiazine	5 exper. 4 control	(o)	
Burris-Myers et al	1942	Letter-letter	Noise		(o)	
Malmo & Finan	1944	Letter-letter	Altitude (18,000 ft.)	24	(o) (-)	No change in number of substitutions. Increase in number of errors.
Brooks, M. M.	1945	Letter-letter	Altitude (18,000 -20,000) Methylene blue	3	(-) (+)	Impairment at altitude Less with methylene blue.
Eckman et al	1945	Letter-letter	Altitude and diet (17,000 ft.)	4	(-)	Decrease in speed 13% greater with protein diet
Grether[1]	1942	Letter-digit	Altitude	24		r(test-retest) ground = .60 - .67.
Grether & Smith[1]	1942	" "	18,000 ft.-15 min.	36	(-)	

[1]Data summarized by Melton (1947).

Table 15 (con.)

SUBSTITUTION TESTS (CODE)

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Gagne & Smith[1]	1943	Letter-digit	Altitude 18,000 ft. -15 min.	26		r(test-retest) 14 vs. 20 = .76 20 vs. 26 = .76
Loucks[1]	1944	Letter-digit	"	36	(?)	Unreliable decrement. r(test-retest) at ground = .79; at altitude = -.22
Campbell (Loucks)[1]	1944	Letter-digit	" plus sulfadiazine	18	(o)	No change with drug.
Cogswell et al	1946	Letter-letter	Diet- Vit.B. deficient 5 weeks	7	(o)	
Berryman et al	1947	Letter-letter	15-18 weeks supplement	7	(-)(?)	Very little decrement but improvement with supplementation.
Guetzkow & Brozek	1946	Symbol-digit	Vit.B. acute deficiency - 21 days	8	(o)	Rate of learning same in deficient and control groups.
Horvath & Freedman	1947	Letter-letter	Cold (-22°F for 8-14 days)	22	(-)	Due to loss of finger dexterity.
Consolazio et al	1947	Letter-letter	Excess CO_2 and decreased O_2 in sealed chamber	(4-77)	(o)	Practice improvement continued. Significant improvement on recovery in normal air.
White	1947		Prolonged flight - 149 hrs. 120 in air	8	(o)	
Fisher & Birren	1945(8)	Letter-letter	Standardization	(Article not seen)		

[1] Data summarized by Melton (1947).

to right until the sum equals a designated number. In a recent modification dexcribed by Melton (1947) the problem consists of a number of horizontal rows of figures, each one constituting a single problem. Four to eight figures are added consecutively until the sum is equal to an underscored number at the left of the line. The subject draws a line after the last number used to obtain the sum. In any strict sense a comparison of results obtained with tests of the present type would require control of many factors, usually neglected in the literature, such as (1) type of mathematical manipulation involved; (2) length of test; (3) horizontal or vertical position of figures; (4) number of elements in each problem; (5) complex requirements such as adding constants, doubling the sum, and the like; (6) aspect of performance selected for measurement, whether speed or accuracy or both, as is the case with most computation tests.

In Table 16 are summarized effects of a large number of different conditions on performance with diverse computation tests taken as a group. It will be observed that altitude and allied conditions are reported to yield decrement in computational performance (Gellhorn 1937; Gellhorn and Joslyn 1937; Barach et al 1947; Grether and Smith 1942; Gagne and Smith 1943; Loucks 1944; Russell 1948; Green et al 1945; Green 1947; Barach, Brookes et al 1943; Eckman et al 1945; Rahn, Otis et al 1946). Exceptional data were obtained by Bagby (1921) using a rebreathing technique, and in one of four subjects by Barach, McFarland, and Seitz (1937) who interpret their inconclusive finding to practice effects. Studies of fatigue and allied conditions are in fairly good agreement that performance on computation tests is not markedly impaired (Robinson and Herrmann 1922; Kleitman 1923; Lee and Kleitman 1923; Weiskotten 1925; Laslett 1928; Ryan and Warner 1936; Dockeray 1915; Whiting and English 1925; Barmack 1938; Hollingworth 1939; White 1947; Muscio 1920). A single exception is offered by Warren and Clark (1937) who report an increased number of blocks in sleep-deprived subjects. Results on noise (Ford 1929; Harmon 1933; Obata et al 1934) are complex. Other findings are given in the table.

Few reliability coefficients for computational tests are available. Melton (1947) places the test-retest reliability of the SAM Addition Test as determined at ground level at .85 to .90, depending on the trials correlated. At altitude, however, the reliability coefficient on test-retest falls to .19. He has further demonstrated with this test, a practice curve which reaches a stable level fairly rapidly. Mace (1935) has shown that performance depends, among other things, on standards adopted by the subjects. Since these differ from subject to subject and from time to time this factor would tend to depress the reliability of the test. Guetzkow et al (1946, 1947) report a test-retest coefficient of .85 for a two-by-one digit multiplication task.

The psychological functions measured by computational tests are variously characterized in the literature. According to Whipple (1914), elements of perception, movement, attention, retention, as well as simple association are all involved in computational performance. Melton's factorial evidence shows the highest intercorrelation between addition and single dimension pursuit, and lowest with code substitution, within the test battery employed. Of a numerical operations test, Guilford (1947, p. 83) reports that "little or no significant variance appears in any factor other than the one so characteristic of this test, and of other mathematical and numerical tests - the numerical factor". Correlations between computational tests and a simple motor function, such as finger dexterity, are low; their correlation with tests of general intelligence is, however, fairly high.

17. Tests of Perceptual Judgment

In tests of perceptual judgment the task is to compare two or more stimulus patterns of some degree of complexity. Although the bulk of such tests are based on vision, a number have been developed which depend on other sensory fields, as the tactile or kinaesthetic. The stimulus dimensions to be judged vary from test to test and include intensity, extent, duration, form and others. Some of the more widely used tests falling under the present category are those of weight judgment, size-weight discrimination, estimation of known size, line bisecting and trisecting, extension of curves, judgment of distance, relative speed, lapsed time, spatial correspondence, and the various form boards. For a discussion of the problems involved in the construction and administration of such tests, the reader is referred to the works of Gibson (1947), McFarland (1946), and Fitts (1947).

With few exceptions, perceptual judgment tests have indicated no decrement in performance under the conditions listed in Table 17. Aside from the work of McFarland (1937-III, 1932) in which time perception and form board manipulation are shown to be influenced at relatively extreme altitudes, and that of Guetzkow and Brozek (1947), in which a small effect on a spatial relations test under acute Vitamin B deficiency has been demonstrated, results have been negative or inconclusive.

Few estimates of the reliabilities of tests of the present sort have been found. Grether (1942) reports that reliability obtained with a line-bisection test was unsatisfactory, possibly due to the subject's lack of knowledge of the results of their performance. Guetzkow et al (1947) find a reliability of .90 (trials 20-21) for a 'flags test' (Thurstone) which depends on 'mental rotation' of the stimulus patterns in order to determine their similarity or dissimilarity. Practice effects with the latter test, while present, are reported to diminish rapidly. The Minnesota Paper Form-board, which is considered by Garrett and Schneck (1933) to measure form and space perception, is stated to have a reliability coefficient of .90.

Table 16

COMPUTATION TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
			A. Mental arithmetic tests			
Hollingworth	1912	Constant increment	Caffeine	16	(+)	
Hollingworth	1914	"	Diurnal variation	15	(+) (-)	Evidence of diurnal change.
Hollingworth	1923-24	"	Alcohol	6	(-)	
Hull	1924	Continuous addition	Smoking		(o) (+)	In accuracy In speed.
Robinson and Herrmann	1922	Multiplication, 2-place by 2-place	Sleep privation (60-65 hrs.)	3	(o)	
Kleitman	1923	Mental arithmetic	Sleep privation (40-115 hrs.)	6	(o)	
Lee & Kleitman	1923	"	Sleep privation (to 112 hrs.)	1	(o)	
Weiskotten	1925	Addition	Sleep privation (3 days)	1	(o)	
Laslett	1928	Addition	Sleep reduction	4	(o)	
Glaze	1928	Multiplication 2-place by 2-place	Fasting (10-33 days)	3	(-)	
Dorcus & Weigand	1929	Continuous addition	Carbon monoxide	5	(o)	
Ryan & Warner	1936	Addition	Driving (8-1/2 hrs.)	6	(-)(?)	Tendency to decrement increased variability.

Table 16 (con.)

COMPUTATION TESTS

Source	Year	Test	Condition	Subjects	Results Code	Results Remarks
Wespi	1935	Kraepelin Arithmetic	Altitude	12		
			(12,000 ft.)		(o)	
	1936	"	(17,000 ft.)		(-)	
Gellhorn	1937	"	Anoxia (rebreathing)	15	(-)	
Gellhorn and Joslyn	1937	"	"	15	(-)	
Baker	1937	Continuous addition	Noisy distraction - suggestion	70		Complex results - suggestion determines reaction to distraction.
Fleming & Goldman	1936	Addition	Alcohol -small doses	17	(o)	
Macht & Macht	1939	Constant increment	Morphine and related drugs	20	(-)	
		Multiplication	Cobra venom		(+)	
		Mixed computation	Caffeine		(+)	
			Amidopyrine and aspirin		(?)	
Tyler, D. B. et al	1947	Mental arithmetic - concurrently with EKG	Sleep privation (50, 75 and 100 hrs.)	12		Change in EEG in sleep-deprived subjects, performing computations.
		B. Addition tests (paper and pencil)				
Dockeray	1915	20 digits in column	Physical work		(?)	Irregular.
Bagby	1921	Addition of digits in line until sum equals specified number	Anoxia (rebreathing)	Pilots	(o)	

Table 16 (con.)

COMPUTATION TESTS

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Carver	1922	Addition of digits in line until sum equals specified number	Smoking		(-)	Increase in errors.
Laird	1925	Adding columns of W. W. forms	Periodicity	112	(-)	Decline during day, and during week.
Whiting & English	1925	Continuous addition of 3's and 4's to a given number	Morning and afternoon	16	(o)	
			90 min. high-speed work	4	(o)	
Eagleson	1927	15-four-place numbers	Monthly periodicity	4 women	(?)	
Ford	1929	Selection and addition of digits from a mixed row	Noise		(-) (o)	Initial transition and then habituation.
Harmon	1933	10 three-place numbers	Noise		(?)	Variability - slight tendency for reduction in speed. Periods of inaccuracy.
Obata et al	1934	4 digits in column	Noise		(+) (-)	Gain in accuracy. Decrement in output.
Davis, R. C.	1936	3 five-place numbers	Aspirin	33	(o)	
Barmack	1938	2 six-place numbers, top one always same	2-hr. work & benzedrine	36	(-) (+)	Progressive decrement retarded by benzedrine.
Hollingworth	1939	Adding digits in W.W. forms	Continuous work - 8 hrs.	6	(o)	

Table 16 (con.)

COMPUTATION TESTS

Source	Year	Test	Condition	Subjects	Results: Code	Remarks
White	1947	Addition	Flight -149 hrs. 120 in air	8	(o)	
Barach et al	1947	Simple arithmetic	Positive pressure breathing at 47,000 ft.		(-)	
Grether[1]	1942	Addition of digits in horizontal line until sum equals specified number	18,000 ft. -15 min.	24	(-)	r(test-retest)= .85 -.90.
Grether & Smith[1]	1942		" "	36	(-)	
Gagne & Smith[1]	1943		" "	26	(-)	
Loucks[1]	1944		" "	36	(-)	r(test-retest) at ground = .88; at altitude = .19.
			Sulfadiazine	36	(o)	
Russell, R. W.	1948	"	18,000 ft. -35 min.	244	(-)(+)	Initial decrement, followed by recovery.
Green et al	1945	"	Altitude and diet (17,000 ft.)	50	(-)	Decrement greater with protein diet.
Green, D. M.	1947	"	Altitude and diet (17,000 ft.)	50	(-)	
C. Multiplication and mixed arithmetical operations (paper and pencil						
Muscio	1920	Mixed	Diurnal & fatigue	34	(+) and (o)	Some diurnal fluctuation.
Carver	1922	Multiplication	Smoking		(?)	
Jersild & Thomas	1931	Mixed	Adrenaline	6	(?)	Trend in direction of decrement

[1] Data summarized in Melton (1947).

Table 16 (con.)

COMPUTATION TESTS

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Vernon & Warner	1932	4-digit mult. and division	Noise		(o) or (+)	
Kleitman	1933	Mult. 8-digit by 8-digit	Diurnal variations	6	(+) (-)	Evidence of diurnal rhythm.
Mace	1935	Simple and complex computation	Incentives			Performance depends upon the standards adopted by the subject.
McNamara & Miller	1937	Mult. 3-digit by 3-digit	Benzedrine	10	(o)	
Shilling and Willgrube	1937	Computation	Increased atmospheric pressure	46	(-)	
Warren and Clark	1937	Alternate addition and subtraction of 3 from integers	Sleep privation (65 hrs.)	4 exper. 4 control	(-)	Decrement shown in increased number of blocks.
Barach, McFarland and Seitz	1937	Arithmetic with slide rule	Altitude (12,000 ft.) (4 hrs.)	4	(-) (?)	Decrement in 3 of 4 subjects.
Knehr	1940	Square roots	Altitude and benzedrine	8	(-) (o)	Greater variability with benzedrine. No difference at altitude until final period.
Barach, Brookes et al	1943	Mult. 3-digit by 3-digit	Altitude (15,000 ft.)	16	(-)	Increase in errors.
Eckman et al	1945	Mult. 5-digit by 5-digit	Altitude & diet (17,000 ft.)	4	(-)	Greater impairment with protein (32%).

Table 16 (con.)

COMPUTATION TESTS

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Rahn, Otis et al	1946	Multiplying 5-digit by 5-digit	Acapnia (30,000 ft.) with pneumolator	10	(-)	Progressive effect as alveolar CO_2 decreases.
Guetzkow et al	1946	Mult. 2-digit by 1 digit (6 alternate forms)	Diet -Vit. B deficiency	8		
			partial		(o)	Rate of learning not affected.
			acute		(-)(?)	Lowered performance in acute deficiency, (10% level).
			supplement		(+)	Improvement with supplement.
Guetzkow et al	1947	(Same as above)	Standardization	48		r(test-retest) = .95 (21 vs. 22 trials)
Fisher & Birren	1945(6)	Computation (mixed addition and subtraction)	Standardization	(Report not seen)		
Consolazio et al	1947	"	CO_2 excess	(4 - 77)	(-)	
			O_2 decrease in sealed chambers		(+)	Significant increment in 60 hr. test on recovery in normal air.

According to Guilford (1947, p. 6) the space factor, which some such tests may be presumed to deal with, is analyzable into "awareness of spatial relations or arrangements; a spatial orientation in which reference to the human body is important," and a second, ill defined factor, "a dynamic function, since it is present in most tasks involving movements of machinery, transformations of objects and changes in position."

18. Miscellaneous Tests of Visual Perception

Tests included within this category form a composite group considered together for little more than purposes of convenient description.

Paper-maze tests, of several kinds, all requiring relatively fine discrimination, have been used by several investigators. Pollock and Bartlett (1932) describe an 'eye-maze' which must be followed with the eye alone, without the use of a pencil. Mazes are presented on a sheet of paper on which are printed three rectangles, each one containing a set of ten mazes. The subject marks with a pencil the exit of each of thirty mazes presented consecutively. Unit-scores are taken in terms of time to complete each 10 mazes; number of errors is also recorded. A slight impairment has been reported by these investigators on this test, with loud noise.

Grether (1942) describes a 'letter-maze' in which the subject is presented with a sheet of typewritten lines composed of A's and C's. The task is to draw a continuous pathway of A's from the left hand top of the sheet to the bottom of the sheet. Twenty 'barriers' occur on a test sheet in each of which there is only one correct crossing-point out of approximately 20 possible choices. Score is the number of barriers crossed in three minutes. Ten equivalent forms of the test differing only in the position of crossing points are available. Learning proved to be virtually a negligible factor in the test and the range of scores adequate. Test-retest reliability computed for trials 2 and 3 is given as .80. However, impairment with altitude, as measured by this test, proved negligible (Grether and Smith 1942).

Tests of reversible perspective have been employed by several workers (Smith 1916; Hollingworth 1939; Ehrenstein[1], Fitts 1947) for detection of deficit under fatigue and anoxia, the combined results of which are uninterpretable or negative. Procedures require the subject to indicate, usually by pressing a key, whenever an ambiguous stimulus such as a staircase, or a nest of cubes appears to change its orientation. Although practice effects are reported to be marked, reliability of these tests may be inferred from a study by Fitts (1947) to be reasonably high.

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[1] Cited by Fitts (1947).

Table 17

TESTS OF PERCEPTUAL JUDGMENTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Judgments of weight and size.			
Hollingworth	1912	Caffeine	16		
Fernberger	1916	Mental work Physical work		(o) (-)	Decrease in precision of judgment of weights.
Farmer, Chambers and Kirk Farmer and Chambers	1933 1936	% Accidents	Industrial workers		Part of battery to detect accident-prone.
Jones et al	1941	Hours of driving	Truck drivers	(o)	
		B. Judgment of length of lines.			
Whiting and English	1925	Morning and afternoon	16 college students	(o)	
Grether[1]	1942	Altitude standardization	14		r(test-retest)= .08 & .39
Grether and Smith[1]	1942	Altitude (18,000 ft.-15 min.)	26	(o)	
		C. Judgment of distance.			
Hemmon, V.A.C.	1919	Normal	300 aviators		Part of battery for flying ability.
Stratton et al	1920	Normal	50 - 70 aviators		Shows promise of prediction.

[1] Data is summarized in Melton (1947).

Table 17 (con.)

TESTS OF PERCEPTUAL JUDGMENTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Stevens, S. S.	1941	Noise (90 and 110 db.)	5	(o)	
Forbes, Dill et al	1937	Carbon monoxide	8	(o)	
		D. Judgment of speed.			
Stratton et al	1920	Normal	50-70 Aviators		Shows promise of prediction of ability to fly.
Forbes	1932	Normal	81 drivers		
Farmer, Chambers and Kirk	1933	% Accident rate	Industrial workers		Part of battery to detect the accident-prone.
Farmer and Chambers	1936	" "	" "		" " "
		E. Judgment of elapsed time.			
McFarland	1937 III	Altitude (3 months)	10	(o) (-)	No change until 17,500 ft.
Glickman et al	1946	Cold and diet -Vit. B.	12	(o)	
Tyler et al	1947	Sleep privation (112 hrs.)	(Not stated)	(o)	

Table 17 (con.)
TESTS OF PERCEPTUAL JUDGMENTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		F. Judgment of spatial relations.			
		1. Flags (Thurstone)			
Guetzkow and Brozek	1946	Diet - Vit. B deficient	8	(o)	No change during partial restriction.
				(-)	During acute deficiency F significant but deterioration only 7%.
				(+)	Rapid improvement on supplement.
Guetzkow and Brozek	1947	Normal	32		r(test-retest) = .90 (20th & 21st trial)
		2. Form Boards.			
McFarland	1932	Anoxia	5	(o) (-)	No decrement until 21,500 ft. (9.70% O_2).
McFarland and Barach	1937	Altitude 12% O_2 10% O_2	32 psychoneurotics 25 normal	(-)	
Carl and Turner	1939	Benzedrine	143	(?)	In general, increase in speed, little effect on accuracy.
Carl and Turner	1940	Benzedrine	38	(?)	
Stevens	1941	Noise (90 and 115 db.)	5	(o)	

Tests of number identities involve presenting the subject with parallel pairs of figures, some of which are identical, others non-identical. The task is to check the numbers, indicating whether they are the same or different. Score is usually given in terms of number of items correctly checked minus the number of errors during an interval time. The intertest reliability of a form of this test is given by Guetzkow and Brozek (1947) as .87 (21st and 22nd trials). Intercorrelations of this test with other tests in their battery, of the type included in general intelligence tests, ranged from .11 to .44. Use of these tests with diet, and a combination of cold and diet, has yielded negative results (Glickman et al 1946; Guetzkow and Brozek 1946). However, Consolazio et al (1947) report a decrement with CO_2 excess and O_2 decrease in sealed chambers.

Two tests of visual illusions were employed by Grether, Cowles and Jones (Fitts 1947) under anoxic conditions with a negative outcome. A group of tests, still in the developmental stage, which deal with illusions perceived under conditions of aircraft flight, such as angular acceleration and 'g', are under investigation by Graybiel and his collaborators (1945, 1946a, 1946b, 1948).

The Clock Test developed by Mackworth (1944, 1948a) presumably samples the psychological functions involved in prolonged visual search required of radar operators. A six-inch pointer moves 360° clockwise over a clear, white sheet in 100 discrete movements. At irregular intervals the pointer skips a full step. The subject is required to push a key whenever this double length movement occurs. A test session of two hours is divided into 20 min. intervals during which 12 double length movements occur, followed by 10 minutes of regular movement. The series is repeated four times. Information concerning results is withheld from the subject during the test period. A decrement in performance was observed after the first half-hour of continuous performance, which was increased under the condition of divided attention, when the subject was required to listen for a telephone message while watching the clock. (See Section II of this report.) Error scores were also shown to be increased by both high temperatures (Mackworth 1948b) and 'chilling' (Ellis 1947) and decreased with benzedrine (Mackworth and Winson 1947). Carpenter (1948) has shown that errors on the clock test correlate with rate of blinking under the fatiguing condition produced by two hours work on the test. On the basis of results obtained with 6 repetitions of the test by 10 subjects, Carpenter (1946) has concluded that practice effects, if present, are obscured by other variations.

Other miscellaneous tests of visual perception are included in the following table with the results obtained under various conditions.

Table 18

MISCELLANEOUS TESTS OF VISUAL PERCEPTION

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
1. Eye maze					
Pollock and Bartlett	1932	Noise		(-)(?) (o)	Slight deficit which quickly disappeared.
2. Letter maze					
Grether[1]	1942	Altitude	24		r (test-retest) = .50 & .80
Grether and Smith[1]	1942	(18,000 ft. - 15 min.)	28	(o)(?)	Loss small and of little significance.
3. Number identities (Thurstone)					
Glickman et al	1946	Cold & Diet - Vit. B	12	(o)	No change in Vit. B diets. Data on cold not clearly stated.
Guetzkow & Brozek	1946	Diet - Vit. B deficient	8	(o)	No change in rate of learning Insignificant deterioration of performance during acute deficiency.
Consolazio et al	1947	CO_2 excess & O_2 decrease in sealed chambers	4 - 77 (37 for 60 hr.)	(-)	In 60 hr. experiment decrement significant. Improvement on return to normal air.
4. Reversible Perspective					
Ash	1914	Fatigue		(-)	Decrease in rate of fluctuation.

[1] Data is summarized in Melton (1947).

Table 18 (con.)

MISCELLANEOUS TESTS OF VISUAL PERCEPTION

Source	Year	Condition	Subjects	Results: Code	Remarks
Smith, M.	1916	Fatigue	3	(-)	Decrease in rate of fluctuation.
Hollingworth	1939	Fatigue	6	(+)	Increase in rate of fluctuation.
Stevens	1941	Noise (90 & 115 db.)	5	(?)	
Glickman et al	1946	Diet - Vit. B and Cold	12	(o)	No change with Vit. B. Effect of cold not clearly stated.
Fitts	1947	Altitude (15,000 ft.) 10 min.	32	(o)	
5. Visual illusions					
Fitts	1947	Altitude (15,000 ft.) 10 min.	32	(o)	
		10,000 ft. - 5 hrs.	10	(o)	
		7 hrs.		(o)	
Graybiel and Clark Graybiel and Hupp Graybiel, Clark et al Graybiel, Clark et al Clark, Graybiel et al Vinacke	1945 1946 1946 1947 1948 1947	Angular acceleration, centrifugal force and other flight conditions	Pilots & Observers		Most of the work is descriptive but the "collimated star" method has possibility of being quantified and applied to related problems.
6. Reading instrument dials					
Fitts	1947	Acceleration 1-1/2 G and 3G	34	(-)	More errors at 3G than at 1-1/2 G.

Table 18 (con.)

MISCELLANEOUS TESTS OF VISUAL PERCEPTION

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		7. Reading tabular numerical material			
Crook, Hoffman et al	1947	Vibration (450/min.) 0.079" D.A. 0.024" D.A. 0.0079" D.A.	26	(o)(-)	Decrement when vibration combined with unfavorable conditions of brightness and type size. Decrement in time but not in errors.
		8. Prolonged visual search ("Clock" test and others)			
Tufts College	1942	Fatigue - due to long hrs. of duty		(o)	
U.S. NDRC	1942	Sleep privation (50 hrs.)		(o)	No decrement when incentives provided.
		Prolonged streneous exercise		(o)	No effect on short tasks.
				(-)	Decrement in tasks of 1-1/2 hrs.
		Noise		(+)	Temporary reduction of decrement.
		Long continued work on task itself		(-)	Decrement due to boredom; could be relieved by incentives, rests, incidents.
Mackworth	1944	2 hrs. on test itself	Groups of 25	(-)	Decrement after first half hour.
"	1948a	Divided attention (telephone message)		(-) (+)	Increased decrement until message received, then increment.
		Special briefing		(o)	

Table 18 (con.)

MISCELLANEOUS TESTS OF VISUAL PERCEPTION

Source	Year	Condition	Subjects	Results Code	Remarks
Carpenter "	1946 1948	2 hrs. on test itself - retests	10 20	(-)	No consistent effect of retests.
Mackworth & Winson	1947	Benzedrine (10 mgm)	24	(+)	Performance maintained at initial level. Fewer missed signals. Speed of response faster.
Ellis	1947	chilling		(-)	
Mackworth	1948b	Heat & Humidity (79^{o} - 97.5^{o} F - E.T.)	46 26	(-)	Greater number of errors. Good performers are less impaired than poor performers

19. Tests of Visual Perception Span

Tests of visual perception span measure the number of elements within a complex stimulus that can be immediately reported by a subject following its momentary exposure. Materials employed are varied, consisting of letters, short words, dots, digits, and the like. The short exposure interval necessary to eliminate eye movements, is usually produced tachistoscopically. The subject reports orally, or sometimes by writing, as quickly as possible, those characteristics of the stimuli specified in the instructions. Strict comparability among these tests would demand control of a number of factors, often unheeded in the literature, such as, preparation of the subject, distance of materials from the eyes, length of exposure, fixation of the eyes, and intensity of background illumination. Scores are usually taken in terms of the largest number of elements that can be grasped by the subject, without error, in a single exposure. For a discussion of methods employed in tests of this type, the reader is referred to Garrett and Schneck (1933) and Chapman and Brown (1935).

In several studies conducted at high altitude, McFarland found a reduction in visual span for words; at lower altitudes the effect is less apparent (1937-I, 1937-III, 1938). Seitz and Barmack (1940), however, have failed to confirm McFarland's findings. Noise (Stevens 1941) and vibration (Coermann 1939) have yielded no significant effect on perceptual span.

No data on the reliability of tests of visual perception span were found. According to the findings of Barmack and Seitz (1940) performance on a test of perceptual span showed a practice trend of considerable magnitude.

20. Tests of Fixation (Immediate Memory)

'Immediate memory' refers to reproduction of stimulus materials, on the basis of a single exposure, when a brief time-interval is interposed between the occasions of presentation and reproduction. Materials consist of forms, dots, letters, words, and the like, which are visually presented, or, in testing auditory memory span, taps or spoken words may be used. The subject's response may be oral or written.

In the standard test of visual 'memory span' the stimulus-patterns are presented to the subject at a fixed rate, each one being exposed for as many seconds as there are elements in the stimulus. Thus, if the presentation contains eight digits it is allowed to continue for eight seconds. Following presentation the subject reinstates as much as possible of what he has seen without support of external cues. Number of elements usually ranges from three to

Table 19

TESTS OF VISUAL PERCEPTION SPAN

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
McFarland	1937 I	Altitude (Rapid ascent)	6	(-)	At 15,000 ft.
McFarland	1937 III	Altitude	10		
		15,000 ft.	(acclimatized)	(?)	Slight decrement, which
		17,500 ft.	3 mos.	(-)	progressively increased.
		20,000 ft.		(-)	
McFarland and Edwards	1937	Flights (approx. 10,000 ft.)	19	(?)	Decrement not significant.
McFarland	1938	Flights (9-12,000 ft.)	8	(?)	
Seitz and Barmack	1940	Altitude (16,000 - 1 hr.)	18	(o)	
		Altitude + benzedrine		(o)	
Barmack and Seitz	1940	Benzedrine	32	(o)	Test-retest shows practice effects.
Stevens, S. S.	1941	Noise (90 & 115 db.)	5	(o)	
Coermann	1939	Vibration (15-1000 Herz)	2 - 12	(?)	May be impairment at small amplitudes. (May be purely visual.)

nine, with fifteen or more trials in the test. Scoring is often accomplished on a point scale, the subject receiving credits, weighted in proportion to degree of difficulty, for each item in a series correctly reproduced. In the auditory form of the test, the subject is commonly required to reproduce combinations of tappings sounded by the experimenter on a series of wooden blocks. The latter test is thereby complicated over the visual since it calls for memory of position as well as number of elements. In either form, the test may be made considerably more difficult by requiring backward reproduction of the stimulus sequence. In a complex variant of the present type of test, Bagby (1921) used 49 miniature lamps arranged in rows of 7 and mounted on a vertical panel. A scattered group of 3 to 7 lamps were lighted for 3 seconds. The subject, following extinction of the lights, designated, on a map corresponding to the possibilities of the presentation, which ones had been lighted on a particular trial.

In a 'location-memory' test (Dorcus and Weigand 1929) the subject is shown slides containing 6 different patterns of circular spots varying in number from 3 to 8. The subjects were required to duplicate the presented pattern on a prepared sheet by filling in those circles which had been shown on the slide. The score is the number of circles correctly filled in minus the number incorrectly marked.

An allied test has been used by Nixon (1946) in a series of experiments dealing with immediate memory for spatial relations. In brief, the method involves showing subjects one or more spots in various positions and at various distances apart on a white circle, and later requiring them to mark the positions on a blank replica of the original circle. Scores are derived directly from errors of estimation.

A further version of an immediate memory test by Finan and Hammond (1942) is believed to admit of increased quantification and control. The subject viewed a small aperture illuminated by a light of given intensity for 2 seconds duration. Either immediately upon extinction of the light, or 15 seconds later, the subject turned a knob which controlled the illumination of a second aperture, in an effort to reproduce the original intensity as closely as possible. A series consisted of 18 trials with four different illuminations presented in random order. A control on subject differences in discriminative capacity was obtained by running a concurrent series of 'matching' trials in which the subject was required to duplicate each of the four standard light intensities (while these were actually present) by controlling the illumination in an aperture immediately adjacent to that in which the original light appeared. A total score was obtained by subtracting the average 'matching' score from the average 'memory'

score. Although the test-retest reliability of this test proved low (.27), preliminary data suggest its sensitivity under extreme conditions of altitude.

Results summarized in Table 20 indicate that the tests of immediate memory employed revealed little or no deficit under the varied conditions of moderate anoxia, smoking, 'fatigue', carbon monoxide and Vitamin B deficiency.

According to Garrett and Schneck (1933) the reliability of tests of memory span has been reported to be high: .84 for auditory digit span and .74 for visual digit span. Nixon (1946) reports that the test-retest results on his version indicate reliable readings from day to day on the same subjects. Practice appears to improve performance to at least some extent. Range of scores yielded by standard tests of memory span has proved to be narrow, suggesting the restricted usefulness of this particular form of immediate memory test.

High intercorrelations have been reported between visual and auditory memory span. Garrett and Schneck (1933) report an intercorrelation of .73 between digit span and number cancellation. A number of studies support a high degree of relationship between tests of memory span and those of general intelligence. In general, immediate memory has been found to correlate only to a small extent with tests of rote memory. In a series of highly suggestive experiments, Nixon (1946) studies immediate memory as a function of a number of variables including delay interval and the number and position of elements. A negative exponential function is suggested to describe results of 'immediate forgetting'.

21. Tests of Memory and Learning

Tests of memory are distinguishable from those in which 'fixation' receives primary emphasis, in terms of the length of time interval interposed between the 'acquisition' and 'reproduction' occasions. In the tests of 'immediate memory' considered within the preceding section, reinstatement followed immediately upon the single presentation of the stimulus materials . In the case of 'memory' as contrasted with 'immediate memory', a longer period is interposed between the presentation and testing events. There appears to be sound evidence for distinguishing between two types of memory, one of which allows the subject, in his effort to reproduce an original situation, to utilize a stimulus-cue which is provided him by the experimenter, and another in which he is required to reinstate the original situation solely on the basis of self-given cues, presumably symbolic. In terms of the operations involved in testing these two kinds of memory, one presents the subject with a stimulus-cue that has been associated on one or more trials with

Table 20

TESTS OF FIXATION (IMMEDIATE MEMORY)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
1. Auditory memory span (Digit span) (Consonant span) (Digits reversed)					
Bagby	1921	Anoxia (rebreathing)	Pilots	(o)(-)	Decrement toward end of rebreathing.
Hull	1924	Smoking	Smokers Non-smokers	(o) (-)	
Gilliland and Nelson	1939	Coffee	5	(?)	
Carl and Turner	1939	Benzedrine	143	(o)	
Carl and Turner	1940	"	38	(o)	
Tyler	1947	Sleep privation (24-112 hrs.)	(488 in total)	(o)	
2. Memory for position of lamps or spots					
Bagby	1921	Anoxia (rebreathing)	Pilots	(o)(-)	Decrement toward end of rebreathing.
Dorcus and Weigand	1929	Carbon monoxide	6	(o)	
3. Knox cube test (position of taps)					
Carl and Turner	1939	Benzedrine	143	(?)	
" " "	1940	"	38	(?)	
4. Repetition of auditory patterns					
McFarland	1937-III	Altitude (acclimatized) 3 mos.	3	(-)	At 17,500 and 20,140 ft.

Table 20 (con.)

TESTS OF FIXATION (IMMEDIATE MEMORY)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
5. Block series memory (Position of colored cubes)					
Malmo and Finan	1944	Altitude	12		Consistent progressive decrement at altitude but not significant beyond 5% level.
		12,000 ft.		(o)	
		15,000 ft.		(o)	
		18,000 ft.		(-)(?)	
6. Number span (Copying numbers on reverse side of sheet)					
Guetzkow et al	1946	Diet - Vit. B deficient - 161 days	8	(o) (?)	
7. Reproduction of light intensities					
Finan and Hammond	1942	Altitude (18,000 ft.)	24	(-)(?)	

another, and is hence known as the method of 'paired associates'. In the second type, whatever material has been acquired during previous training must be reinstated without such associated cues. Following common usage we may designate the first type of performance as 'associative memory', and the second as 'reproductive memory'. Learning is a generic concept which includes both fixation and retention and which emphasizes comparison of amounts of material that are reproduced by the subject at various points in an extended practice sequence. In a strict sense, any test whatever may be examined from the standpoint of improvement with practice. Learning is hence a category which is not coordinate with a classification of tests according to 'performance' as technically defined to mean behavior at a given moment. Tests falling under the present heading of memory and learning are ordered according to the distinctions drawn immediately above. An account of the variables to be considered in tests of the present type may be found in McGeoch (1945).

A paradigm of the paired associate method is given by a study of Hull (1924), in which a series of unfamiliar geometric figures are presented to the subject paired with a list of nonsense syllables. The subject is required to respond to each figure by speaking the appropriate nonsense syllable into a voice key. Pairs of items are presented singly until the list is completed. Serial cues are broken up by presenting the cards in different order from trial to trial. Scores are derived from the number of correct reproductions after a fixed number of practice trials.

From Table 21 it may be seen that altitude is consistently reported to yield a decrement in associative memory (Bagby 1921; McFarland 1937-I and 1937-III, 1938; Malmo and Finan 1944). It appears, however, that the decrement occurs only under relatively extreme conditions of anoxia. With the exception of alcohol (Hollingworth 1923-24) other conditions described in the table yielded no marked change in paired associate performance.

Intratest reliability of the paired associates technique employed in their study was given by Malmo and Finan as .85 (corrected).

Another test employed by Hull (1935) provides an example of the reproductive memory type. Sixteen lists of nonsense syllables of sixteen items each are repeatedly presented to the subject up to the point of mastery, the number of trials required constituting the score. The subject reproduces as many of the syllables as possible without benefit of associated stimuli presented by the experimenter, although self-produced serial cues may be assumed to play a substitute role.

Aside from decrements reported by McFarland at high altitude and by Mead (1939) and Cattell (1930) with alcohol, results obtained with reproduction memory tests have revealed little alteration in performance under the conditions arrayed in Table 21.

Materials and techniques employed by these tests are probably too diverse to permit any general statement of reliability.

In so far as tests of associative and reproductive memory have both lumped together the factors of fixation and reproduction, they may be regarded as measures of learning. In the tests employed by Edwards (1941a) and by Keys and his collaborators (1945) primary emphasis is on changes resulting from repeated practice rather than on reproduction per se. Consequently these tests are to be classified as learning rather than as memory. No clear cut differences in rate of learning were revealed by these tests under conditions of sleep privation and Vitamin B deficiency.

22. Tests of Associative Relations and Reasoning

Tests falling in the present group emphasize the requirements of facility and speed of making controlled associated responses. Depending on the instructions given, the subject responds to a verbal stimulus with a word opposite, analogous, or otherwise related to the stimulus word. The verbal response given, in some cases, together with latency, is recorded. In tests of reasoning, both complexity and degree of control of associations are presumably increased.

A first group of tests, dealing with production of words from a fixed number of letters presented to the subject yields mainly negative findings as shown in Table 22. In a common form of tests of the present type, Guetzkow and Brozek (1946, 1947) require the subject to form as many words as possible beginning with a given letter prescribed by the tester, in a unit time. Test-retest reliability of this test is reported as .77 (21st and 22nd trials). Although practice effects are prominent, performance is reported to become stable enough for testing, by the 21st trial. No decrement on this test was observed under conditions of Vitamin B deficiency. A more complex variant of the test, developed by Reynolds and Shaffer (1943) involves presenting a sheet with two columns of words to the subject. In the first column are 32 eight-letter words, in the second, the same words in different order, with the letters scrambled and with one letter omitted. Scores are taken in terms of the number of words formed in a unit time. A decrement on this test is reported with administration of sulfathiazole.

From Table 22 it is also seen that isolated investigations employing tests of logical relations and reasoning, report deficit under conditions of 'fatigue' (Smith 1916) and alcohol (Hollingworth 1923-24). With caffeine (Hollingworth 1912; Flory and Gilbert 1943)

Table 21

TESTS OF MEMORY AND LEARNING

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
A. Paired-Associates method.						
Smith, M.	1916	Pairs of nonsense syllables	Fatigue	(Few)	(?)	Not a useful test.
Dockeray	1915	Pairs of nonsense syll.	Fatigue	6	(-)(?)	
Bagby	1921	Color-name & number	Anoxia (rebreathing)	Pilots	(-)(?)	Decrement only at later stages.
Hollingworth	1923-24	Pairs of nonsense syll.	Alcohol	6	(-)	
Hull	1924	Nonsense syll. & geometric forms	Smoking	Smokers Non smokers	(?)(+) (?)(-)	In speed of repetition trend to increment. In ability to reproduce.
Weiskotten	1925	Pairs of nonsense syll.	Sleep privation (3 days)	1	(o)	
McFarland	1937-I	Pairs of nonsense syll.	Altitude (ascents by train)	6	(-)(?)	Means significantly poorer.
McFarland	1937-III	Pairs of 4-letter words	Altitude (grad. adaptation)	10		
			9,200 ft.	10	(o)	
			15,440 ft.	10	(o)	Errors greater.
			17,500 ft.	9	(-)	
			20,140 ft.	5	(-)	

Table 21 (con.)

TESTS OF MEMORY AND LEARNING

Source	Year	Test	Condition	Subjects	Results Code	Remarks
McFarland	1938	Pairs of 4-letter words	Altitude (rapid ascent)	200	(-)	At 14,000 and above, very marked at 18,000 and 20,000 ft.
			Altitude + 3% CO_2	4	(+)	3% CO_2 improved performance.
McFarland & Edwards	1937	"	Flights (9-12,000 ft.)	19	(?)	Consistent decrement but not reliable.
McFarland & Dill	1938	"	Altitude (Comparative)	10 3	(-)	Decrement greater in unacclimatized subjects.
Malmo & Finan	1944	Pairs of 2-syll. adject. (immediate and delayed recall)	Altitude	12		r(intratest)= .74 - .88
			12,000 ft.		(-)(?)	
			15,000 ft.		(-)(?)	r(test-retest)= .54 - .86.
			18,000 ft.		(-)	Delayed recall more reliable.
Guetzkow & Brozek	1946	Word-number pairs	Diet-Vit. B	8		
" " "	1947		restricted -151 days		(o)	r(intratest) = .79
			Acute - 23 days		(-)(?)	
Glickman et al	1946	"	Diet-Vit.B and Cold	12	(o)	
B. Reproductive memory for lists of nonsense syllables.						
Jones, J. R.	1933	Series of 12 nonsense syll.	Aspirin		(o)	
Hull	1935	Series of 16 nonsense syll.	Caffeine	8	(?)(-)	Slight retardation.

Table 21 (con.)

TESTS OF MEMORY AND LEARNING

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
McFarland	1937-III	Series of 10 nonsense syll.	Altitude (adaptation 3 mos.)	10		
			9,200 ft.	10	(o)	
			15,440 ft.	10	(o)	
			17,500 ft.	9	(-)	
			20,140 ft.	4	(-)	
Mead	1939	Artificial language	Alcohol	6	(-)	
C. Reproductive memory for meaningful material.						
Laird	1925	Meaningful material	Diurnal and weekly variations	112	(-) (+)	Evidence of diurnal decline. Weekly peak on Wednesday.
Cattell	1930	Factual material	Caffeine (0.4 gm.)	50	(-)	Large doses cause decrement.
			Alcohol (20 gm.)		(-)	
			Caffeine (0.2 gm.)		(+)(?)	Individual differences with small doses.
			Alcohol (10 gm.)		(-)(?)	
D. Reproductive memory and learning (various methods).						
Carl and Turner	1939	Learning "D"	Benzedrine	143	(o)	On immediate recall.
" " "	1940	Learning "Z" Sentence Memory		38	(o)	
Edwards	1941	Learning typing & telegraphy Ranchbury memory test and others	Sleep privation (100 hrs.)	19 exper. 10 control	(?)	Results inconclusive or irregular.

Table 21 (con.)

TESTS OF MEMORY AND LEARNING

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Keys et al Guetzkow & Brozek	1945 1946	(1) ACE repeated (2) Porteus maze repeated (3) Cattell's CMS (4) Battery of primary mental abilities (5) Cancellation (6) Number span (7) Perseveration	Diet-restricted Vit. B - 161 days Acute deficiency - 23 days	8	(o)	No change in rate of learning, although level of performance was lowered at certain conditions. (See entries under various test categories.)

and benzedrine (Flory and Gilbert 1943) slight increments in performance are reported. Other studies dealing with sleep privation (Lee and Kleitman 1923), tobacco (Carver 1922), and aspirin (Davis 1936), have yielded negative or inconclusive results.

Reliability coefficients of .80 - .95 are given by Garrett and Schneck (1933) for an opposites test, and of .88 for a test of difficult analogies. Standardization data for various types of logical relations are given by Woodworth and Wells (1910-11).

Spearman holds that tests of controlled association are among the most heavily loaded with a 'g' factor. A number of studies cited by Garrett and Schneck bear out a high degree of relationship between tests of opposites and analogies and those of general intelligence.

23. Tests of Perseveration (Change of Set)

The rationale of tests under this category is apparently the role of 'stable set' or interference of one type of performance with a subsequent one in many types of inefficient or maladaptive performance. Tests of perseveration are characterized by changing the task-instruction to the opposite of what it is habitually, or what it has been immediately preceding. Variant forms of this test are based on the interposition of opposed tasks alternately, within the same test. Scores are taken in terms of speed or accuracy, on the two parts of the test, or occasionally in terms of a qualitative analysis of errors. In a perseveration test employed by McFarland (1937-I) the subject was required to add and subtract alternately a series of digits. The subjects were then instructed to perform the mathematical opposite to what the plus and minus signs indicated. A further example of a complex 'directions' test which appears to have strong perseverative components has been used by Loucks (cf. Melton 1947). The subject is required to enter a letter beside a two-place number in accordance with seven different instructions such as "If the number is odd, write the letter C", or "If the number is odd and divisible by three, write the letter D", or "If the number is odd or even and is divisible by five, write the letter B", etc. Included within the present group are two tests of mirror-tracing (Louttit 1943; Peters 1946), so classified, because although a path-tracing component is clearly present in these tests, the emphasis as determined by the indices of performance chosen for measurement is on the inability to reverse a well established eye-hand coordination.

Results obtained with perseveration tests are summarized in Table 23. McFarland (1937-I, 1937-III) has demonstrated deficit in performance of the present sort at altitudes above 15,000 feet.

Table 22

TESTS OF ASSOCIATIVE RELATIONS AND REASONING

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
A. Word production, word completion, verbal fluency.						
Pollock and Bartlett	1932	Making words beginning with and containing only specified letters	Noise	80	(-)(?)	Discontinuous noise more marked than continuous.
Carl and Turner	1939	Word production	Benzedrine	128	(o)	Little change.
" " "	1940	" "	"	38		
Hecht and Sargent	1941	Anagrams - disarranged words	Benzedrine	91	(o)	
Reynolds & Shaffer	1943	Omitted letters	Sulfathiazole	73	(-)	May be idiosyncrasy.
Guetzkow & Brozek	1946	First letters (Thurstone)	Diet -Vit. B -184 days	8	(o)	
Guetzkow & Brozek	1947	"	Standardization	48		r(test-retest) (21 & 22) = .77
Kleemeier & Kleemeier	1947	Word completion (Griffits)	Benzedrine	32	(o)	
B. Logical relations						
Hollingworth	1912	Opposites	Caffeine	16	(+)	
Hollingworth	1914	Opposites	Diurnal variations	15	(+) (-)	
Smith, M.	1916	Assoc. words	Fatigue	3	(-)	
Lowson	1923	Analogies & opposites	Anoxia	5	(-)(?)	Small number of observations.

Table 22 (con.)

TESTS OF ASSOCIATIVE RELATIONS AND REASONING

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Lee & Kleitman	1923	Opposites	Sleep privation (112 hrs.)	1	(o)	
Carver	1922	Opposites	Smoking		(?)	Difficult to get equally difficult lists.
Hollingworth	1923-24	Opposites	Alcohol	6	(-)	
Davis, R. C.	1936	Opposites	Aspirin	33	(o)	
		C. Tests of reasoning.				
Seward & Seward	1936	Syllogistic reasoning	Alcohol	12	(?)	
Andrews	1940	"	Benzedrine	20	(o)	
Hecht & Sargent	1941	Reasoning (Thurstone)	Benzedrine	91	(o)	
Flory & Gilbert	1943	Analogies (Freeman & Flory)	Benzedrine Caffeine Placebo	129	(+)(?) (+)(?) (+)(?)	Suggestion played part.

Kleemeier and Kleemeier (1947), employing a variety of perseveration tests have shown a consistent improvement in performance with benzedrine. Other findings with conditions of dietary deficiency (Guetzkow and Brozek 1946), altitude (15 min. at 18,000 feet) (Loucks 1944) and repetitive work (Wyatt and Langdon 1937) showed no impairment.

No reliability estimates for this type of test were found, possibly because of the ambiguous meaning of the usual reliability statistics as applied to tests of this sort. According to Guilford (1947, p. 564), "The hypothesis that change of set is a fundamental trait that can be measured by a battery of tests was not proved to be justified by results achieved".

24. Miscellaneous Performance Tests

Several tests which do not fall in any of the categories outlined in the preceding summarizations are considered under the heading of 'miscellaneous' tests.

A first type of test is based on deterioration in quality or quantity of handwriting. Interest in this effect is, however, less on the aspect of motor efficiency than on that of the 'central' integrative mechanisms assumed to be involved. In the experiment of McKenzie, Riesen et al (1945) the cessation of handwriting under extreme anoxic conditions is regarded as a limit of performance. Writing under such conditions degenerates into a scribble and stops at a point which is considered to be the 'end-point' of consciousness. The validity and sensitivity of the test is seen in the finding that for each 1000 feet increase in altitude between 25,000 and 32,000 feet, the duration of handwriting is decreased by approximately 20 seconds. A number of other investigators have shown handwriting deterioration as a function of altitude (see Van Liere 1942). The table includes only those references where an attempt was made to quantify the observations (McFarland 1938; Hemingway 1944).

In a complex 'coding' test described by Mackworth (1948a), the subject is required to place a large and a small block on each of a number of pegs, in accordance with coded instructions. Decrement in performance on this test under high Effective Temperature has been demonstrated in the same study.

Cattell (1941) has devised a 'Cursive Miniature Situation Test' which makes use of a moving strip of paper on which are printed a succession of lines and other geometric patterns. The subject performs certain prescribed tasks on the figures during their exposure through a small aperture. According to its designer, this test, by virtue of standardized, prearranged difficulties, frustrations and demands on judgment, measures such qualities as quickness

Table 23

TESTS OF PERSEVERATION (CHANGE OF SET)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Sowton and Myers	1928	Number checking	Monthly periodicity	29 women	(o)	Complex results.
McFarland	1937-I	Perseveration arithmetic symbols lines	Altitude (rapid ascent)	6	(o) (-)	No change until 15,440 ft.
	1937-III	Same	Altitude	10 (acclimatized)	(-)	At 15,440 and above. Errors marked at 20,000 ft.
McFarland	1938	Same	Altitude	30 normal 35 psycho-neurotics	(-)	Greater in psycho-neurotics.
Wyatt & Langdon	1937	Perseveration-inverted S triangle cancellation	Repetitive work and boredom	Industrial workers		Scores had no relationship to boredom.
Farmer & Chambers	1939	Perseveration-copying letters	% accident rate - car drivers	Motor car drivers		Part of battery for accident-prone.
Loucks[1]	1944	Directions test	Altitude 18,000 ft.-15 min.	36	(o)	
Campbell (Loucks)[1]	1944	" "	" plus sulfadiazine	36	(o)	
Guetzkow & Brozek	1946	Wittman's Dash-opposites	Diet-Vit.B deficient	8	(o)	

[1] Data is summarized in Melton (1947).

Table 23 (con.)

TESTS OF PERSEVERATION (CHANGE OF SET)

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Kleemeier & Kleemeier	1947	1.Multiplication 2.Select. subst. 3.Arith. speed 4.Letter series 5.Over and under 6.Pencil & Paper motor	Benzedrine	32	(+) (+) (+) (+) (+)(?) (+)(?)	1% level 1% " 5% " 5% "
Louttit	1943	Mirror drawing[1]	Normal	86 "problem" 82 control	(-)	Difference between groups
Peters	1946	" "	"	141 "problem" 91 control	(-)(?)	Socially maladjusted tend to solve problem more slowly.

[1] See also Path-Tracing tests for mirror drawing tests.

of decision, resourcefulness, excitability, patience, restraint, enterprise, etc. The split-half reliability of the test is reported to be high, .90 (corrected). A significant difference between the performance of normal and psychotic subjects has been demonstrated with the test. Performance is stated not to be related to age, intelligence or education. McFarland and Franzen (1943) report, on the basis of use of the test on aviators, that it has potential as a selection test for aircraft personnel, but point to the burdensome scoring as a disadvantage. Keys et al (1945) have used the present test to indicate possible effects of dietary privation with inconclusive results.

A 'stress test' developed by Freeman (1945) requires the subject to perform two disparate acts under conditions of distraction. On the right side of a panel is presented a series of simple discrimination problems which are responded to at the subject's own rate of response. On the left side of the same panel are shown a series of numerical, form, and letter equations which would not be difficult to follow if they were presented alone. The subject signals whether the equation is right or wrong by pushing the appropriate one of two levers with the feet. The number of correct discriminations and problems is integrated automatically by means of counters. The 'stress' component is provided by auditory distractions to which the subject is forced to listen since comments relevant to performance are included among irrelevant ones. A third task added (reproduction of rhythm code patterns) resulted in the refusal of a 'majority' of subjects to continue with the task. There appears to be some evidence that neurotic subjects show greater disturbance than normals both during and following the test.

A further test devised by Farmer and Chambers (1926, 1929, 1933) is based on the movement of a set of levers which control the appearance and disappearance of certain numbers on a dial. The subject strives to produce prescribed combinations of figures involving the manipulation of not fewer than three levers. Scores are taken from the time required to achieve the correct result. Pollock and Bartlett (1932) have utilized this test in a study of the effects of noise with the finding that an initial decrement gave way to unimpaired performance.

The relative neglect of motivational factors in performance has evoked criticism from a number of investigators who have attempted to construct tests of various kinds that might overcome this lack. The 'Guidit Test', developed by Pollock (1929) presumably provides the subject with more task-incentive than most performance tests. A small metal ball must be guided up an inclined plane with a fine knitting needle set in a handle. Between the bottom of the board and the goal at the top are 21 holes large enough for the ball to drop through, and 7 barriers to be circumvented. A system of marks is employed to credit moving the ball a given distance; time consumed is also recorded. No decrement in this performance was found by Pollock and Bartlett, under noise. McFarland (1932) using the test, reports effects on performance of individuals under anoxic conditions.

A pin-ball machine reported by Melton (1947) yielded negative results at altitude.

Table 24

MISCELLANEOUS PERFORMANCE TESTS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Continuous reaction test (Cursive Miniature Situation) (CMS).			
Cattell	1941	Normal Distractions Social encouragement Haste Reward Punishment	49 normal 46 psychiatric patients 50 delinquents (all female)		r (split-half) = .90 r (sub-tests with total) = .80 to .96. Significant difference between normals and psychotics. Less difference between normals and delinquents. Not correlated with age, intelligence or education.
McFarland and Franzen	1943	Normal	Groups of Naval aviators		Test promising for selection purposes. (C.R. = 2.57) but scoring too difficult.
Keys et al	1945	Diet - Vit. B. partial restriction 161 days.	8		Rate of learning somewhat inferior during restricted period but not significantly.
Guetzkow and Brozek	1946	23 days acute deprivation	8		During deprivation no significant change in over-all performance. Special scores - emotional deteriorated but not psychotic.
Brozek, Guetzkow and Keys	1946	10 days - supplementation			
		B. Freeman's "stress" test.			
Freeman	1945	Test description and relation to "stress" and neuroticism.			

Table 24 (con.)

MISCELLANEOUS PERFORMANCE TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		C. Hand writing[1]			
McFarland	1938	Altitude	200		
		14,000 ft.		(-)(?)	Beginning at 14,000 ft.,
		16,000 ft.		(-)	fairly great at 16,000 and
		18,000 ft.		(-)	18,000 ft. with rapid ascents
Hemingway	1944	Altitude	31		
		30,000 ft.		(-)	In 123 sec. after O_2 disconnected.
		35,000 ft.		(-)	In 72.6 sec. after O_2 disconnected. Reversal in 5 sec. after oxygen reconnected.
MacKenzie et al	1945	Altitude 20,000 and above	1042	(-)	End of writing is good index of useful consciousness at 25,000 ft. and above.
		D. Coding Test - (form board with coded instructions).			
Mackworth	1948b	Heat (79° to 97.5° E.T.)	12	(-)	Significant decrement at E.T. 87° F. and above.
		E. Number-setting test.			
Farmer and Chambers	1926	Incidence of accidents	Groups of workers		Part of battery to predict accident-prone.
Farmer and Chambers	1929				
Farmer, Chambers and Kirk	1933				
Pollock and Bartlett	1932	Noise	4	(o)	Some effect at first which disappeared.

[1]Includes only those references in which an attempt was made to quantify the observations, either by scoring samples or by timing exact point at which writing stops.

Table 24 (con.)

MISCELLANEOUS PERFORMANCE TESTS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		F. Tests devised to have an intrinsic interest - high motivation.			
		1. Ball and slot test.			
Mace	1935	Incentives			Performance influenced by knowledge of results, standards adopted by subject, instructions, etc.
		2. "Guidit".			
Pollock	1929	Long spells on test itself	3	(?)	Qualitative observations of value.
Pollock and Bartlett	1932	Noise		(o)	
McFarland	1932	Anoxia due to rebreathing	14	(-)	Individual differences.
McFarland and Barach	1937	Altitude (10 & 12% O_2)	32 psychoneurotic 25 normal	(-)	
		3. Pinball machine.			
Melton Loucks	1947 1944	Altitude (18,000 ft. for 15 min.)	36	(o)	

25. Complex Tests Simulating Aspects of Flight Performance

References listed in the accompanying table provide representative samples of tests which simulate one or more aspects of flight performance. Within this group are placed 'trainer tests' which involve bodily displacement in a miniature fuselage, requiring coordinated movements of a set of controls by the subject who in order to fly a 'course' must maintain the balance of the apparatus in response to visual, kinaesthetic and other stimuli. Detailed information on apparatus, procedures and reliabilities of several tests of the present type, including the Link Trainer, are given by Melton (1947). D. R. Davis (1942, 1948), using a Silloth Trainer, has shown no progressive deterioration of performance during a five-hour test period. However, an increase in the number of good and bad 'patches' of performance was observed.

Also falling in the category under discussion is the 'Cambridge Cockpit' described by Craik (1940), and used by Drew (1942, Bartlett (1943, 1947), and Davis (1946a, 1946b, 1947, 1948). The subject is given verbal instructions along with a written summary of task requirements and is then put through a series of exercises involving maneuvers as well as straight and level flying. The total amount of movement of each of the controls is summated and graphic records of movements of the aileron and elevator are taken. The apparatus resembles a Link Trainer but differs with respect to controls and immobile fuselage. Under the condition of noise no change in accuracy of control was observed, but there was evidence of greater variability in the magnitude of displacement of the controls. For a further consideration of results obtained with this apparatus see Section II of this report. Validity of this test has been established in some measure by demonstrating a correlation between scores and accident proneness within a small group of pilots.

As a matrix of test ideas the 'Cambridge Cockpit' has proved its value and has generated, among others, the Skilled Response Test (Davis 1946a, 1948) which appears to involve some features of discrimination reaction time combined with rate pursuit as well as conflict. A stimulus appears either to the right or left of a display consisting of three vertical lines. A pointer manipulated by an aircraft-type of control must be displaced from the neutral position either to the right or left by moving the control correspondingly, setting up a rate of movement of the needle proportional to the magnitude of displacement of the control. The subject's task is to bring the pointer into alingment with the correct lateral line by accurately timing his return of the control to the neutral position. The response requires accurate timing if overshooting and the necessity for secondary compensatory movements are to be avoided. The magnitude of displacement of the control and accuracy of alignment are measured. Data are available to indicate that complicating the presentation by lighting the lateral lines simultaneously, especially to the same intensity (discrimination conflict), results in greater displacement of the control, together with

exaggerated overshooting and increase in the frequency of secondary responses. When noise was added as a condition, no change in the mean accuracy of performance was observed, but variability of displacement was increased. These studies have possible implications for analysis of performance in general in their derivation from a complex but presumably well controlled situation, rather than from a gross job analysis, as well as in their emphasis on variability and qualitative aspects of performance rather than merely on accuracy or speed of performance.

The Stevens Coordinating Serial Reaction Test (Stevens 1941) is superficially analyzable into a complex discrimination reaction test in combination with a two-dimensional non-compensatory pursuit test. The subject manipulates stick and rudder type aeroplane controls which govern the movement of a rectangular spot of light on a screen. The spot of light is moved along a number of curvilinear pathways presented on the screen, in order to extinguish lights placed at the ends of the pathways. The target lights placed at the corners and center of the screen flash on in irregular order, one at a time, following completion of a trial-response. Score is given in terms of time required to extinguish 50 lights; time spent off the pathway is also recorded by means of a counter. Stevens, using the present test, reports a 5% decrement in performance under the condition of loud noise. Pincus and Hoagland (1943) have shown that pregnenalone improves performance over the level normally attained after two hours of work on the apparatus. According to these investigators the Coordinating Serial Reaction Test has a protracted practice curve and fails to eliminate the possibility of rhythmic performance which might be assumed to allow the subject to compensate for deficit.

A final test discussed under the present heading is the Dial-Matching Test (Hoffman and Mead 1943) in which the subject is required to (1) align the pointer of an inner dial with that of another, outer dial, whose movements are determined by the movements of an irregular cam; (2) keep track of deflections of 12 ammeters by throwing a toggle-switch when a deflection is noted; (3) signal at the end of every ten minutes of interval passage; (4) indicate by a signal when a miniature aeroplane arrives at various stopping points represented on a map; (5) indicate by a signal when a miniature Zeppelin appears in any of four quadrants of the map. Failure to make any response correctly causes the aeroplane to stop in its flight until the appropriate adjustment is made, resulting in longer time required for the plane to arrive at a terminal point. Score is obtained automatically in terms of the time and errors made by the subject in his effort to prevent the plane from being delayed. No significant changes were observed during four hours of performance on the test (Clark et al 1943). The nature of the present task is highly complex, involving elements of pursuit, discrimination and attention, as well as integration of behavior-segments under a goal.

In the judgment of the writers, the chief justification of the 'miniature situation' test is in its assumed relationship to a criterion situation to be predicted. Therefore, this type of test, while not necessarily unrelated to performance, may not be specifically designed to measure decrement. A further objection is that such tests scarcely push the problem any farther toward the ultimate goal of analysis of the psychological components which underly the complex performance product. On the other hand, the British use of the miniature situation as a semi-controlled source of leads to be exploited independently under isolated conditions, appears to yield fruitful results.

Table 25

COMPLEX TESTS SIMULATING ASPECTS OF FLIGHT PERFORMANCE

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Tests in "trainers" of various types (Link Trainer and others).			
Davis, D. R. " " "	1942 1948	5-hr. Test in Trainer	7 pilots	(-)	No progressive deterioration but increase in "bad patches" (periods of errors).
		B. "Cambridge Cockpit".			
Craik	1940	Apparatus description	-		
Drew	1942	2-hrs. on apparatus	140 pilots	(-)	Decrement in side-slip and air-speed = 45%.
Bartlett	1943	" " "			Omission of tasks.
Davis, D. R.[1]	1948	" " "	34 pilots	(-)	Analysis of type of deterioration.
Davis, D. R. " " Bartlett	1946a 1946b 1947 1947	46 min. on apparatus	355 pilots	(-)	268 slight or no changes = normal. 87 not normal, 59 "overactive", 28 "inert".
		Noise	40 pilots	(o) (?)(-)	No change in mean performance but decrement shown in increased variability of response.
		Normal	383 pilots		Validity for prediction of accidents, and "operational fatigue" - lower scores.
		C. Skilled Response Test.			
Davis, D. R.	1948	Complicated or ambiguous stimulus	69 pilots	(-)	Greater displacement and greater overshoot, return response less accurate.
	1948	Noise	40 pilots	(o) (?)(-)	No change in accuracy but greater variability in size of displacements.

[1] Summarizes data of other reports.

Table 25 (con.)

COMPLEX TESTS SIMULATING ASPECTS OF FLIGHT PERFORMANCE

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		D. Stevens Coordinating Serial Reaction Test.			
Stevens, S. S.	1941	Noise - 115 and 90 db.	5	(-)	5.4% decrement in time and errors.
Pincus and Hoagland	1943 1944	Pregnenalone	5		Pregnenalone improved performance.
		E. Dial-Matching Test (Complex task).			
Hoffman and Mead	1943	Normal	5	(o)	No decrement during 4 hours.
Clark, R. E., et al	1943	Sleep privation (50 hrs.)	9	(-)	
		F. "Stress" Tests 1. The Controls Confusion Test			
Melton	1947	Oral criticism		(?)	Results indeterminate.
		2. Multiple Control Stress			
Melton	1947	Noise	56	(?)	Scores questionable.

SUMMARY OF RESULTS AND GENERAL CONCLUSIONS OF SECTION I

Compilation of test methods and findings given in the preceding parts of the report suggest several conclusions of possible value to future research efforts concerned with the testing of performance decrement.

(1) From Table 26, which recapitulates test data by the condition of altitude, it appears that the availability of tests showing gross performance decrement under this condition does not pose a serious problem. In fact, despite wide variations in anoxic environments, and tests employed to measure their effects, virtually all types of tests yield a decrement in performance, providing the anoxic condition is sufficiently extreme. Evidence presented supports the view that the effects of anoxia are reflected ubiquitously throughout the range of behavioral functions measured by performance tests. A similar statement, based on considerably less evidence, however, can be made of the conditions of heat and cold, as is shown in Table 29. By contrast, noise and/or vibration appears from Table 28 to have pronounced effects on very few behavioral functions as measured. Fatigue, as will be seen in Section II of the present report, has no clear cut effects on many dimensions of behavior. Effects of conditions superimposed on altitude, as summarized in Table 27, likewise appear to require especially sensitive measurement in order to be made manifest (assuming that the conditions have an effect).

Again, in spite of dissimilarities in tests classed under the same categories, consistencies in the data suggest that certain types of tests are more affected by the condition of altitude than are others. The obvious possibility of a simple relationship between sensitivity and degree of complexity of test is not supported by the findings, although it appears that neither an extremely simple type of test, such as strength of grip, nor an extremely complex one, such as general intelligence, reveals marked decrement. Steadiness and steadiness-aiming indicate impairment in efficiency at altitudes as low as any at which effects have been demonstrated. It may be significant that the pursuit tests, which may also be presumed to have a strong 'precision' component, are influenced at lower altitudes than most other types of test. Of possible interest, too, is the fact that, among the more complex tests which employ errors as an index of scoring, such as code-substitution and computation, most show impairment at moderate altitudes. In the cases of color naming (Bills 1937; McFarland 1937 and series), code substitution (Malmo and Finan 1944), and computation (Warren and Clark 1937; Barach, Brookes et al 1943), where direct comparison between time and error scores is possible, the latter prove more readily influenced. Such comparisons, however, are only partially justified, since errors contribute mediately to time scores in many types of tests. Within the most complex tests, reproductive memory is, according to the fragmentary evidence summarized in the table, less sensitive to anoxia than associative memory, possibly as a result of increased availability of serial cues to the subject, in the former. Perceptual tests, including perceptual span, and tests of 'immediate memory' do not place among the most sensitive. Results summarizing effects of various conditions superimposed on altitude (see Table 27) are difficult to interpret as in, or out of line with the findings on altitude alone.

Table 26

COMPOSITE RESULTS OF THE EFFECTS OF ALTITUDE ON PSYCHOLOGICAL TESTS

Code:
0 = no effect; – = decrement; ? = inconclusive; U = unknown

Test	Simulated altitude (in feet)						Sources
	10,000 or lower	10,500 to 12,500	13,000 to 15,000	15,500 to 17,500	18,000 to 20,000	Higher	
Simple Reaction Time	o	o	o	o	o	–	McFarland 1932, 1937-I; Wespi 1933, 1936.
Tapping Tests	o	o	o	o	–	–	Bagby 1921; Lowson 1923; Malmo and Finan 1944.
Arm-Hand Steadiness	o	–?	–	–	–	–	Malmo & Finan 1944; Eckman et al 1945; Otis Rahn et al 1946; Rahn & Otis 1947.
Body sway	o	o	–?	–	–	–	Birren, Fisher et al 1946; Barach, Brookes et al 1943.
Steadiness Aiming	o	o	–	–	–	–	Bagby 1921; Malmo & Finan 1944; Melton 1947.
Tests of manipulation and dexterity	o	U	U	–	–	U	Barach, Brookes et al 1943; King et al 1945; Green et al 1945; Smith, Seitz & Clark 1946; Green 1947; Melton 1947; Russell 1948; Smith 1948.
McDougall-Shuster dotting test	o	U	U	–	–	–	McFarland 1937-I, 1937-II.
Pursuitmeter Tests	U	U	–	–	–	–	McFarland 1932; Green et al 1945; Barach, Brookes et al 1943; Pincus & Hoagland 1943; Green 1947; Melton 1947.

Table 26 (con.)

COMPOSITE RESULTS OF THE EFFECTS OF ALTITUDE ON PSYCHOLOGICAL TESTS

Test	Simulated altitude (in feet) 10,000 or lower	10,500 to 12,500	13,000 to 15,000	15,500 to 17,500	18,000 to 20,000	Higher	Sources
Discrimination reaction time	o	o	o	-?	-?	-	McFarland 1932, 1937-I, 1937-II; McFarland & Dill 1938; Wespi 1933, 1936; Melton 1947; Bagby 1921; Bills 1937.
Color Naming - speed	o	o	o	o	o	-	McFarland 1937-I, 1937-II;
errors	o	o	o	-	-	-	Bills 1937.
Card sorting Tests	o	o	o	o?	-?	-	Bagby 1921; Lowson 1923; West et al 1944; Gerstell 1946; Hoffman et al 1946.
Cancellation Tests	U	U	U	U	U	-	Gellhorn 1937; Gellhorn & Joslyn 1937.
Substitution Tests	o	o?	-?	-	-	-	Johnson & Paschal 1920; Lowson 1923; McFarland 1937-I, 1937-III, 1938; McFarland & Dill 1938; McFarland & Edwards 1937; Knehr 1940; Malmo & Finan 1944; Brooks 1945; Eckman et al 1945; Melton 1947.
Computation Tests	o	-?	-	-	-	-	Bagby 1921; Barach, McFarland & Seitz 1937; Knehr 1940; Barach, Brookes et al 1943; Green et al 1945; Green 1947; Eckman et al 1945; Melton 1947; Russell 1948.
Perseveration and Directions Tests	o	o	o	-?	-?	-	McFarland 1937-I, 1937-III; 1938; Melton 1947.

Table 26 (con.)
COMPOSITE RESULTS OF THE EFFECTS OF ALTITUDE ON PSYCHOLOGICAL TESTS

Test	Simulated altitude (in feet)						Sources
	10,000 lower	10,500 12,500	13,000 15,000	15,500 17,500	18,000 20,000	Higher	
Tests of Perceptual Judgments	U	U	o	o	-?	-	McFarland 1932, 1937-III; Melton 1947.
Tests of Visual Perception and Illusions	U	U	o	U	o	U	Fitts 1947; Melton 1947.
Visual Perception Span	o	o	-?	-?	-	-	McFarland 1937-I, 1937-III, 1938; McFarland & Edwards 1937; Seitz & Barmack 1940.
Tests of Fixation and Immediate Memory	o	o	o	-?	-	-	Bagby 1921; McFarland 1937-III; Finan & Hammond 1942; Malmo & Finan 1944.
Memory Tests (Paired Associates)	o	-?	-?	-	-	-	McFarland 1937-I, 1937-III, 1938; McFarland & Edwards 1937; McFarland & Dill 1938; Malmo & Finan 1944.
Reproductive Memory Tests	o	o	o	o	-	-	McFarland 1937-III.
Tests of Logical Relations and Reasoning	U	U	U	U	-?	-?	Lowson 1923.
Miscellaneous Tests							
Hand writing	o	o	-?	-?	-	-	McFarland & Barach 1937; McFarland 1932, 1938.
Pinball	U	U	U	U	o	U	Hemingway 1944; MacKenzie et al 1945; Melton 1947.
Guidit					-	-	

Table 27

RESULTS OBTAINED WITH ADDITIONAL CONDITIONS SUPERIMPOSED ON SIMULATED ALTITUDE

Code:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate.

Test	Conditions	Results	Sources
Arm-Hand Steadiness	Diet (protein or carbohydrate) at 15,000 & 17,000 ft.	(-) (Greater with protein diet)	Eckman et al 1945.
	Hypocapnia at 30,000 ft.	(-)	Otis, Rahn et al 1946.
	Glucose at various altitudes	(o)	Rahn & Otis 1947.
	Carbon monoxide at various altitudes	(o)	Vollmer et al 1946.
Body Sway	Carbon monoxide at various altitudes	(o)	Vollmer et al 1946.
Steadiness Aiming	Sulfadiazine at 18,000 ft.	(o)	Melton 1947.
Tests of Manipulation and Dexterity	Sulfadiazine at 18,000 ft.	(o)	Melton 1947.
	Diet (protein or carbohydrate or fasting) at 17,000 ft.	(-) (Greater with protein or fasting)	King et al 1945; Green et al 1945.
Pursuit Tests	Sulfadiazine at 18,000 ft.	(o)	Melton 1947.
	Pressure breathing equipment at 46,500	(-)	" "
	Methylene blue at 18,000 ft.	(+)	Brooks 1945.
	Diet (protein or carbohydrate at 17,000 ft.	(-) (Greater with protein)	Green et al 1945.
	Pregnenalone and fatigue at altitude	(+) with pregnenalone	Pincus & Hoagland 1943, 1944.
Discrimination Reaction Tests	Increased CO_2 (3%) at various altitudes	(+)	McFarland & Dill 1938; McFarland 1938.
	Hypocapnia at 30,000 ft.	(-)	Otis, Rahn et al 1946.

Table 27 (con.)

RESULTS OBTAINED WITH ADDITIONAL CONDITIONS SUPERIMPOSED ON SIMULATED ALTITUDE

Test	Conditions	Results	Sources
Color Naming	Increased CO_2 (3%) at various altitudes	(+)	McFarland 1938.
Substitution Tests	Benzedrine at various altitudes	(o)	Knehr 1940.
	Increased CO_2 (3%) at various altitudes	(+)	McFarland 1938; McFarland & Dill 1938.
	Methylene blue at 18,000 ft.	(+)	Brooks 1945.
	Diet (protein and carbohydrate) at 17,000 ft.	(-) (Greater with protein diet)	Eckman et al 1945.
Computation Tests	Pressure breathing at 47,000 ft.	(-)	Barach et al 1947.
	Diet (protein and carbohyarate) at 17,000 ft.	(-)	Eckman et al 1945; Green et al 1945.
	Benzedrine at various altitudes	(o)	Knehr 1940.
	Hypocapnia at 30,000 ft.	(-)	Otis, Rahn et al 1946.
	Sulfadiazine at 18,000 ft.	(o)	Melton 1947.
	Increased CO_2 at various altitudes	(+)	Gellhorn 1937; Gellhorn & Joslyn 1937.
Visual Perception Span	Benzedrine at 16,000 ft.	(o)	Seitz & Barmack 1940.
Memory Tests (Paired Associates)	Increased CO_2 (3%) at various altitudes	(+)	McFarland 1938; McFarland & Dill 1938.

Table 28

EFFECTS OF NOISE AND/OR VIBRATION ON PSYCHOLOGICAL TESTS

Test	Results	Sources
Simple Reaction Time Tests	(o)	Coermann 1939.
Tapping Tests	(o)	Stevens 1941.
Arm-Hand Steadiness Tests	(?)	Coermann 1939; Stevens 1941.
Body Sway	(?)	Stevens 1941.
Aiming (Marksmanship)	(o)	Stevens 1941.
Tests of Manipulation and Dexterity	(-) with non synchronous regular noises; (o) with irregular loud noises	Pollock and Bartlett 1932.
Pursuit Tests	(o) Rotary pursuit (-) Multidimensional pursuit	Stevens 1941.
Discrimination Reaction Time, Including Complex Coordination and Serial Tests	(o)	Lewis 1943; Stevens 1941.
Card Sorting	(o)	Pollock and Bartlett 1932; Stevens 1941.
Cancellation	(-)(+)(?)	Obata et al 1934; Burris-Meyers et al 1942.
Substitution Tests	(o)	Stevens 1941; Burris-Meyers et al 1942.
Computation Tests	(+)(o)(?)	Baker 1937; Ford 1929; Harmon 1933; Obata et al 1934; Vernon and Warner 1932-33; Lewis 1943.

Table 28 (con.)

EFFECTS OF NOISE AND/OR VIBRATION ON PSYCHOLOGICAL TESTS

Test	Results	Sources
Tests of Perceptual Judgment	(o)	Stevens 1941.
Tests of Visual Perception[1]	(-)(?)(o) (+) temporary	Pollock and Bartlett 1932; Coermann 1939; Stevens 1941; Tufts College 1942; Crook, Hoffman et al 1947.
Visual Perception Span	(o)(?)	Coermann 1939; Stevens 1941.
Tests of Associative Relations and Reasoning	(-)(?)	Pollock and Bartlett 1932.
Miscellaneous Tests		
Number Setting	(o)	Pollock and Bartlett 1932.
Guidit	(o)	" " " "
Complex Tests Simulating Some Aspect of Aircraft Flight		
Skilled Response Test	(o) Accuracy (-) Greater variability in size of displacements	Davis, D. R. 1948.
Coordinating Serial Reaction Test	(-)	Stevens 1941.

[1]Vibration affects reading of tabular numerical material, chiefly when combined with unfavorable conditions of illumination and size of type.

Table 29

EFFECTS OF HIGH AND LOW ENVIRONMENTAL TEMPERATURES ON PERFORMANCE ON PSYCHOLOGICAL TESTS

Code:
(-) = decrement; (o) = no effect; (?) = inconclusive.

Test	Conditions	Results	Sources
Tapping Tests	Differential diets and clothing at -20° F	(-)	Keeton et al 1946; Mitchell et al 1946; Glickman et al 1946.
Arm-Hand Steadiness	Same	(?) Highly variable	Keeton et al 1946; Mitchell et al 1946.
	CO_2 excess at 85° E.T. (hot tropical)	(-) Difficult to assess effects of heat apart from CO_2 excess.	Consolazio et al 1947.[1]
Body Sway	"	(-) "	" " " "[1]
Aiming (3-hole coordin.)	Humidity	Complex	Stecher 1916.
Path Tracing Tests	Differential diets and clothing at -20° F	(-)	Keeton et al 1946; Mitchell et al 1946; Glickman et al 1946.
Tests of Manipulation and Dexterity	Same	(-)	Same; also Horvath and Freedman 1947.
	Heat (82° - 91°)	(-)	Weiner and Hutchinson 1945.
Pursuitmeters[1]	Combined effects of heat, humidity and air movement	(-) critical temp. for decrement is 87° F, E.T.	Mackworth 1947, 1948b; Carpenter 1947a, 1947c.

[1]Consolazio et al (1947) refer to a study done at the Naval Medical Research Institute (see Pace et al 1943 under references not available) utilizing a series of tests to assess performance in hot spaces which probably separates the effect of heat from the effects of excess CO_2 combined in the available study.

Table 29 (con.)

EFFECTS OF HIGH AND LOW ENVIRONMENTAL TEMPERATURES ON PERFORMANCE ON PSYCHOLOGICAL TESTS

Test	Conditions	Results	Sources
Discrimination Reaction Tests	Differential diets and clothing at -20°F; extended periods at -22°F	(-)(o)	Keeton et al 1946; Mitchell et al 1946; Horvath and Freedman 1947; Glickman et al 1946.
Substitution Tests	Extended periods at -22°F	(-) Due to loss of finger dexterity	Horvath and Freedman 1947.
Tests of Perceptual Judgment	Diet (Vit.B) and cold of -20°F	Results not clearly reported	Glickman et al 1946.
Tests of Visual Perception	Same	Same	Same
Clock Test	Combined effects of heat, humidity and air movement	(-) Critical temp. for decrement is 87°F, E.T.	Mackworth 1948b.
Miscellaneous Performance Tests			
Coding Test	Same	(-) "	Mackworth 1948b.
Wireless Telegraphy	"	(-) "	Mackworth 1948b, 1946.
"Pull" Test	"	(-) "	Mackworth 1947.
A.H.4 (Intelligence Test)	"	(o) "	Carpenter 1947b.

(2) A survey of the field emphasizes throughout the need for standardization of tests employed to detect deficit. Few instances can be found in the literature in which a given test, even when it has been demonstrated to possess reasonably adequate reliability and sensitivity characteristics for most purposes, has been exactly duplicated by subsequent investigators. In so far as alterations in testing procedures represent progressive improvement, they are to some extent justified. All too often, however, it seems apparent that test variations result from a lack of familiarity with the extant body of knowledge on decrement testing, or worse yet, from lack of appreciation of the necessity to control as many relevant factors as possible. Workers in fields allied to psychology, who are understandably unskilled in the use of tests of the present type, are particularly guilty of the latter offense. Psychologists might well settle on a battery of performance tests designed to sample the major dimensions of performance, in so far as they can be identified at present, by the most efficient techniques currently available. The resulting gain in comparability of data might well compensate for the sacrifice of technical progress entailed.

(3) Results presented in the study contraindicate the widely held view that a single test can be considered an 'index' of 'psychomotor performance' in general. Different tests are observed to behave differentially under the same environmental condition, and the same test is noted to be influenced differentially under dissimilar conditions. Intercorrelations between tests judged similar on intuitive grounds prove, for the most part, to be relatively low. This point is seen dramatically in the case of such a simple function as strength of hand grip (see Table A-7) which may not be assumed to measure strength in general, nor general muscular tone, nor, in fact, anything more than the strength of the particular members tested.

(4) Attempts to interpret test functions make especially apparent the need for an adequately founded approach to the basic factors underlying performance. This lack of fundamental classificatory principles goes beyond mere logical nicety, since it stands in the way of any attempt to cope with the practical problem of designating a battery of tests which can be relied on to sample the major dimensions of performance. While distinctions can be made in terms of testing operations, little basis is provided for weighting those which are significant and others which can be regarded as negligible. Some guidance is given by fragments of factorial and intercorrelational evidence but the grouping of factors is still far too narrow to provide a useful conceptual framework. Little is accomplished by grouping the tests under such conceptual categories as 'discrimination', 'association', 'logical relations', 'change of set', and the like, both because of the high degree of overlapping of these functions in many tests and because of their unempirical basis. Needed studies aimed directly at the problem of isolating component functions could

be accomplished by successive experiments within the same testing situation, in which factors of presumed significance are systematically varied. A promising start along the lines suggested has been made by Melton's coworkers (1947) in studies comparing the sensitivity of four pursuitmeters of different degrees of complexity under constant conditions. In another approach designed to obtain basic information related to performance tests, Cockett (1947) has systematically investigated the relationship between complexity and reliability of serial reactions of certain types. On the basis of this study, the interesting hypothesis is advanced that reliability increases as a function of degree of integration of the response required by the task. It is believed that a fruitful research program could be undertaken by utilizing, for example, a reaction time situation which could be adapted to permit variations in complexity of reaction, in type of instruction given, in types of stimuli to be discriminated, in the succession of response, and many other variables, with all other factors held constant. Such functions as discrimination reaction, conflict reaction, perceptual judgment, change of set, could be studied with the possibility of relating the various types of functions with each other directly and with a maximum of control.

(5) The greater sensitivity of errors as an index of scoring, at least under some conditions, suggests several interesting lines of speculation in view of recent work done by the Cambridge Applied Psychology Unit. In a number of studies, time measures, by themselves, proved to show less decrement in performance than more complex measures in which errors are weighted. Thus Davis (1948), using prolonged performance in the Cambridge Cockpit as a fatiguing condition, has shown decrement in terms of the ratio of total duration of errors to the number of movements of the controls. Two types of 'abnormal' reactions to fatigue have been demonstrated, one in which the control movements are high in relation to duration of errors, and another in which duration is high, relatively, to number of movements. Qualitative analysis of errors has proved to yield highly suggestive results.

It is significant that the Cambridge Cockpit studies which were designed to give information concerning kind and duration of errors showed deterioration in performance while the complex task of Hoffman and Mead (1943) did not reveal decrement during an equivalent or longer test period. One factor in this difference may be that in the latter test a failure to respond caused the machine to stop and thus direct knowledge and immediate correction of errors was possible; duration of errors was probably a negligible factor during the total test period and omission of tasks unlikely. In the former studies it was shown not only that the period before compensation for errors became significantly longer during the course of the test period, but that some tasks were omitted entirely.

(6) Variability of response as a further dimension of scoring has been noted by Davis (1948) as well as by a number of other investigators. (McFarland 1937, series; Ryan and Warner 1936; Green 1947; and others.) An additional method of analysis is suggested by Mackworth (1948b) who reports differential decrement between groups of good initial performers and those subjects who performed more poorly initially.

Interpretation of deficit in terms of 'blocking', 'conflict' and 'disintegration' of behavior by the Cambridge investigators suggests a possible line of investigation to test the applicability of the conflict analysis of the Yale group to problems of performance decrement. A more detailed analysis and evaluation of these studies is included in Section II of the present report.

SECTION II

STUDIES OF FATIGUE, LOSS OF SLEEP, APPREHENSION AND STRESS

INTRODUCTION

No attempt has been made to define 'fatigue' for the reason that the term has no generally accepted meaning. Detailed reviews of recent concepts may be found in the recent books by Bartley and Chute (1947), and Carmichael and Dearborn (1947). We have undertaken rather to steer clear of controversial definitions by employing such terms as decrement, or deterioration in performance. In those cases where the deterioration has affected the integrated personality use has been made of the customary phrase, operational fatigue. Otherwise the term 'fatigue' has been carried in single quotes. We review (1) studies with tests administered after subjects have engaged in activity which is presumably 'fatiguing'; (2) studies of deterioration during the progress of the task itself; (3) studies employing stimuli introduced to heighten stress; (4) studies of deterioration in the performance of tasks simulating flight; and (5) studies of operational fatigue.

Studies with Tests Administered after the Subjects have Engaged in Activity Presumably Fatiguing.

1. After Sleep Deprivation

Absence of sleep has not been found to result in significant decrement in such tasks as (1) simple reaction time (Patrick and Gilbert 1896; Lee and Kleitman 1923; Cooperman, Mullin and Kleitman 1934; Edwards 1941; and Tyler 1947); in (2) tapping performance (Patrick and Gilbert 1896; Robinson and Herrmann 1922; Husband 1935; Katz and Landis 1935; Warren and Clark 1937; Edwards 1941; and Tyler 1947); in (3) stationary arm-hand steadiness (Cooperman et al 1934; Edwards 1941; Tyler 1947); in (4) cancellation (Lee and Kleitman 1923; Weiskotten 1925; except for Tyler 1947 after prolonged vigil); in (5) discrimination reaction (Patrick and Gilbert 1896; Lee and Kleitman 1923; Cooperman et al 1934; Husband 1935), except that the Tufts College 1942 study obtained decrement after 50 hours, and Tyler (1947) obtained a decrement on a 10-minute test after 60 hours sleep privation, although there was none on a 2-minute test. Other tests in which scores are not lowered by loss of sleep are (6) letter naming (Patrick and Gilbert 1896; Robinson and Herrmann 1922; Kleitman 1923); (7) arithmetical computation (Robinson and Herrmann 1922; Kleitman 1923; Lee and Kleitman 1923; Weiskotten 1925; Laslet 1928), with the exception that Warren and Clark (1937) report 'blocking' after a 65-hour vigil in a test involving alternate addition and subtraction; nor was there

decrement in (8) time judgment (Tyler 1947), in (9) immediate memory (Tyler 1947), in (10) an opposites test (Lee and Kleitman 1923), or (11) in a paired associates memory test (Weiskotten 1925), after three days deprivation.

In the case of the following tests results have been inconsistent, some studies showing decrement, others no loss after sleep deprivation: (1) Body sway. Lee and Kleitman (1923), Laslett (1928), and Cooperman et al (1934), all found no decrement, Tyler (1947) found insignificant decrement and the results of Husband (1935) and Edwards (1941) were indeterminate. In (2) aiming, Robinson and Herrmann (1922) found no decrement after 65 hours of sleep privation, but Edwards' (1941) results were indeterminate. In (3) color naming, Lee and Kleitman (1923) report decrement in a long series test but not in a short one. Cooperman et al (1934) report no decrement after 60 hours deprivation, but Warren and Clark (1937) report an increase in errors after 65 hours. In (4) a pursuit test there are two studies: Husband's (1935) report shows no loss, and Laslett's (1928) results are indeterminate. Two studies of (5) a logical relations test give inconsistent results, Smith (1916) reporting loss of efficiency, but Lee and Kleitman (1923) finding no loss after 112 hours of sleep privation. In two early studies of (6) reversible perspective (Ash 1914 and Smith 1916), 'fatigue' prolonged the rate of the intervals between fluctuations of equivocal figures, but Hollingworth (1939) found that from the beginning of each run the rate of fluctuation increased from 25 to 50 per cent, the curves nearly paralleling the curves reporting the subject's feeling of strain. The results obtained by Edwards (1941) with reference to (7) typing and telegraphy, (8) the Ranchburg memory test, and (9) an intelligence test were inconclusive. In the case of those who took alternate forms of the American Council on Education (ACE) Intelligence Test, five subjects practically maintained their initial score after 96 hours of sleep privation and two even improved their scores, whereas the majority of the 16 subjects showed a decrement after 48 hours. In four other studies (Robinson and Richardson-Robinson 1922; Laslett 1928; Husband 1935; Katz and Landis 1935) there was no decrement in test intelligence after various amounts of sleep deprivation. In the tests of (10) code substitution four studies give indeterminate results (Laslett 1924 and 1928; Weiskotten and Ferguson 1930; and Husband 1935).

Studies of eye movements after sleep deprivation have not obtained consistent results. Miles (1929) and Miles and Laslett (1931) report a slowing of (11) saccadic movements and (12) frequency of blinking in subjects who were very sleepy after being deprived of sleep for 66 hours. After keeping subjects on a similar vigil, Clark and Warren (1940) obtained no uniform change in (13) the number of fixations, in (14) regressions per line, in (15) binocular adjustments, or in (16) reading time. In fact, in some cases, performance scores were higher on the final tests. They attributed the changes that did occur not to the sleep deprivation of 65 hours but to temporary failure to overcome "the greater subjective threshold of attention and effort".

Tyler's (1947) study of sleep deprivation which extended to 112 hours found no decrement in (17) critical fusion frequency.

In the Tufts College studies (1942), (also Hoffman and Mead 1943, and Clark et al 1943), subjects were submitted to 50 hours of sleep deficit, in addition to a 30-mile hike, after which they were tested for visual discrimination, reaction time, eye-hand coordination, other similar sensori-motor coordination tests, stereo-ranging and azimuth tracing. Most of these tests, although requiring keen observation were essentially simple and discrete in nature. The performances required either momentary attention and response, or only a short period of continuous work. Under these conditions there were no material decrements in performance. When, however, subjects were required to remain attentive for an hour and a half to a prolonged continuous task, there was a measurable decrease in efficiency. Tyler (1947) included administration of the Rorschach Test in the composite used with service men submitted to long period of sleep deprivation. No alteration in the Rorschach responses were apparent after 112 hours of vigil.

2. After Hours of Driving

One method of testing for 'fatigue' has been to compare the results on tests of short duration of subjects who have engaged in a specific type of work for contrasting periods of time. An example of this type of investigation is reported by Jones et al (1941). Significant decrements in performance appeared in the following tests, listed in order of relative loss: (1) tapping speed, (2) manipulation or manual coordination, (3) body sway, (4) simple reaction time, (5) manual steadiness, and (6) critical frequency of flicker fusion. Other tests which failed to yield consistently significant differences between the hours-of-driving groups and those who had driven recently were (7) a simulated driving test, (8) resistance to glare, (9) speed of eye movement, and (10) accuracy in aiming (where there was a non-graded decrement). There was no loss in estimation of the size of a dollar bill and fifty-cent piece. In the test of strength of grip the majority of those who had driven ten hours scored higher than those who had not driven since their last period of sleep.

Two other studies report the effects of tests taken after extended periods of driving. Ryan and Warner (1936) report decrements in (1) body sway, (2) arm-hand steadiness, (3) aiming steadiness, (4) arithmetical computations and (5) color naming; Swope (1933) reported decrement in arm-hand steadiness.

3. After Repetitive Work

Tests of various sorts administered after subjects have been engaged in activity presumably 'fatiguing' have given inconsistent results. Dockeray (1915, 1922) had his subjects engage in 'mental work' of various sorts, including the multiplication of 3-place numbers. There was subsequently some lowering of scores in (1) a paired associates test with nonsense syllables and in (2) the discrimination of sounds. On the other hand, Whiting and English (1925) found no decrement in (3) judging the lengths of lines in the afternoon as compared with the morning White (1947) administered (4) code substitution and (5) arithmetical computations after his subject had completed the exacting task of flying around the world in 147 hours. There was no decrement in his subject's performance. A 'fatigue run' of 18 hours involving marching, calisthenics, and military exercises involving a minimum of hand work, however, did result in a decrement in (6) hand grip (Fisher and Birren 1946). With the test of (7) critical fusion frequency, Brozek and Keys (1944) found no change after an hour of exercise; a result which was also obtained by Graybiel et al (1943) with pilots after the daily flying schedule. Other studies, however, have reported a decrease in frequency after 'fatigue'. Simonson and Enzer (1941) found a decrement paralleling the subjective report of fatigue after the working day. Henry (1942) reported a decrease in the fusion frequency, and Lee (in Jones et al, 1941) reported decrement after three hours' work with a microscope, as well as after hours of driving.

Several workers have reported an increase in (8) the frequency of blinking after continuous use of the eyes, as in reading (Luckiesh and Moss 1937, 1940; Hoffman 1946, and Carpenter 1948). This finding, however, has not been confirmed by Bitterman and his colleagues (1945, 1946, 1947), nor by Carmichael and Dearborn (1947).

Studies of Deterioration Occurring During the Progress of the Task Itself.

It being obvious that there is a limit to the length of time one can continue to work without a period of rest, the problem is to note the conditions which facilitate lengthening the work period without ultimate loss of efficiency. (1) Fernberger (1916) found an increase rather than decrement after testing ability to discriminate lifted weights for a period of an hour. (2) Muscio (1922b), with himself as subject, used an aiming test and a pursuit test; two spells with each for a total stretch of 10 hours 20 minutes. In the first three of the four divisions of the test session, there was a gradual and continuous improvement up to the end of the third hour; in the fourth, accuracy increased for about three-quarters of an hour, after which there was a steady decrement

amounting to about 60 per cent. Muscio's conclusion was that inaccuracy was a function of the rate rather than of the duration of the work. (3) Vernon (1926) used these aiming and pursuit tests and added two others: paper-folding and maze-tracing, employing two subjects. In the pendulum test, there was a decrease during the second hour of a three-hour test, followed by either a levelling off or an increase in the third hour. Results in the aiming test were indeterminate. In paper-folding there was a slight increase in amount done, accuracy remaining fairly level through a 3- or a 4-hour stretch. In the maze test, similarly, accuracy and output held up through 4-hour stretches, even when there were two a day. Afternoon shifts were, however, less efficient than the morning periods, and considerable boredom was reported, periods of boredom synchronizing with records of inaccuracy. (4) Pollock (1929) tested one subject with the "Guidit Test", for 4-hour stretches, after 60 odd preliminary sessions of shorter duration. In all periods of one hour or more, accuracy tended to decrease in the second as compared with the first half of the period. Accuracy remained fairly constant, however, after the first hour even in spells of 8 hours, and speed increased in the second half of the sessions. Feelings of tiredness were accompanied by a decrease of about 10 per cent in accuracy, but they were not marked by significant changes in speed. (5) Bills (1935, 1937), who was studying fluctuations in energy output, tested color and form naming in periods of 30 minutes and an hour. He found an increase in the length and the frequency of 'blocks' with increasing duration of the test period. (6) Laird (1933) found a decrement after a 4-hour period of testing with a dotting machine, the amount varying according to the nature of an accompanying noise. In this case, it is impossible to tell what the effect would have been without the noise. (7) Barmack (1939) reports a decrement in a pursuit test after two hours of work. In 10 of the 15 subjects this was accompanied by a report of boredom, as indicated on a self-rating sheet. (8) Lindsley (1943-44) recorded the results when radar operators continued A-scan oscillograph operation continuously for four hours. There was a progressive loss in the detection of signals and in the accuracy of determining the azimuth or bearing of targets represented by the signals. He noted that occasional prolonged periods of operation may be served without appreciable loss of efficiency. This conclusion is not entirely unequivocal, however, since factors of initial adjustment in the 4-hour period of operation and of learning may have masked the fatigue effects. (9) Pincus and Hoagland (1943) obtained a decrement in a "targetmeter" on which subjects were tested for four hours, and (10) Brozek, Simonson and Keys (1947), measuring acuity of vision in a test requiring the recognition of letters, report consistent and progressive decrement, with increasing variability, in a 2-hour test period. (11) Hollingworth (1939), on the other hand, reports that in an 8-hour test of number cancellation, practice effects masked any possible decrement; and (12) Philip (1939, 1940), who had subjects engage in continuous tapping for 6 or 7 hours at approximately maximum rate, found a decrement of only 6.7 per cent.

(13) Mackworth (1944, 1948a) discovered that the introduction of a 'tension' factor significantly affected the scores for accuracy in the 'clock test'. Subjects were informed that at some time during the 2-hour test a 'message' would arrive. Under these conditions there was a decrement that was larger than was usual - until the 'message' was received. However, the message 'dramatically reduced' the number of missed signals, raising the average number for the third half-hour to a standard usual with fresh subjects. He attributes the added increment in errors to the 'tension', and the improvement which followed receipt of the message to 'release of tension'.
(14) In the test by Clark et al (1943) in Dial-Matching (see Hoffman and Mead 1943 for description of apparatus), subjects watched dials continuously for 4 hours, aligning a pointer while keeping track of the deflection of a dozen ammeters. There were no significant changes either of improvement or decrement, a result which was attributed to adequate motivation.

(15) In Hoffman's (1946) 4-hour test of continuous 'easy and light' reading, sample records were taken at the end of each half-hour, but the subjects were not informed as to when records of their achievement would be made, nor informed as to their progress. Under these conditions the number of lines decreased significantly, a decrement showing up at the end of the first half-hour. The number of blinks increased after the first hour. (16) In a subsequent study (Carmichael and Dearborn 1947), in which Hoffman participated, subjects were required to read continuously for six hours. Some of the material consisted of book pages, some of microfilm. Continuous records were made of the eye movements, including blinking. In no one of the measurements was there a significant decrement and there was no increase in the rate of blinking, even though the task was increasingly unpleasant for some of the 40 subjects. The experimenters attribute the achievement to adequate motivation of the subjects who were kept informed concerning their records and were paid $4.50 for each 6-hour session.

Studies of Stimuli Introduced to Heighten Stress.

Some evidence of the effect on test scores when stimuli are introduced which might be expected to increase the 'tension' of the subjects is furnished by the AAF Research Program (Melton 1947). Employing some of the standardized tests used for the classification of candidates, two major modifications in the stimulus complex were introduced. The first consisted of loud sounds and/or verbal threats of failure and criticisms, supplemented by a digit memory test beyond the candidate's memory span; the second consisted of interruptions of the air supply.

The tests on which the experiment was tried with the introduction of these modifications were (1) arm-hand steadiness and of aiming (designated respectively as Steadiness under Pressure Test, and Aiming Steadiness Test); (2) a peg board test (Conflicting Manipulation Test),

with mouse traps inserted between the pegs; (3) the SAM Complex Coordination Test, and (4) the Two-Hand Coordination Test. The method of air-interruption, which was used with the last two mentioned tests, involved fitting the subjects with the face-piece of a gas mask. Scores made under air-deprivation were compared with scores obtained in the course of normal processing, the test having been introduced as an extra following the six standard processing tests. In the tests administered under air-interruption there was some decrement in the scores. On the other hand, the addition of verbal 'stress' stimuli and 'distracting' mental activity, did not greatly influence the results. In the Arm-Hand (Static) Steadiness Test the scores were actually better (though not significantly) than under normal conditions, and in the Aiming Steadiness Test scores also improved slightly.

In the case of the peg-board (Conflicting Manipulation under Pressure Test) but two 2.5-minute trials were administered, a number insufficient to determine whether or not the distractions produced deficit in performance. In actual fact, efficiency in manipulating the pegs was greater under pressure than without it, and better scores were made in the second trial under pressure than in the first trial (Melton 1947).

In connection with two of the AAF Research studies, experimental situations are reported in which it was presumed to be possible to obtain data concerning the influence of stress. In the first of these studies a Controls Confusion Apparatus was employed with the Observational Stress Test. The assumption was that the test was sufficiently complicated to arouse heightened tension without introducing any extraneous distractions. The assignment requires the subject to get all seven of a set of airplane controls correctly adjusted simultaneously. The Stick, Pedal and "T" controls each have ten contact positions, the "R" control, four; the other three controls, two each. These capital letters each correspond to those on the lights, except for "R", which is connected with a buzzer.

The Observational Stress Test employed the same apparatus, but administration of the test differs in one respect. The subject in a room alone is subjected to oral criticism of his performance. No data are reported comparing scores made under criticism with those in which subjects were not being criticized, nor are the data reported by which comparison can be made between the scores on the succeeding trials (the first two of which were of 3-minute duration, the last of two minutes).

The Multiple-Control Stress Test consisted of six tasks, each selected to represent part of a work sample of flying, and the test so arranged that whenever the candidate exceeds a given tolerated margin of error in any one of the tasks a distinctive and unpleasant sound on an earphone notifies him of his failure. The tasks are progressively more difficult. There were eight 1-minute trials, which progressively increased in difficulty from the third to the

sixth trial. The results which were available for but 56 civilian pilot trainees were considered highly questionable because of "the distortion in the scoring system". No data are available with reference to any possible deterioration in test performance.

Grip Tension. Scores representing the amount of tension involved in grasping 'the stick' were obtained for the normal four 2-minute trials in the Complex Coordination Test. It was found that grip-tension scores were not significantly lower when the candidates were being retested. However, the pressure scores decreased during the course of the test. "This is in line with expectations based on laboratory studies of muscular tension changes during learning and continuous performance" (Melton 1947, p. 163).

Muscle-Action Potential Tests. Reference is here made to action potential studies as representing a variety of psychophysiological methods which were tried experimentally in the AAF toward the close of the war. A method for summating action potentials was employed which has high reliability (.95). Records were made while administering the Multidimensional Pursuit Test (Melton 1947) for six 1-minute trials, separated by 15-second rest periods. During the course of the test there was a marked drop in the action potential index between the first two and the second two trials, but no further drop thereafter. However, the candidates given experimental tests at Psychological Research Unit No. 2 "were informed that the score made on the experimental tests did not count in any way as regards their ultimate classification for aircrew duties...whereupon come candidates entered the test with an audible sigh of relief" (Melton 1947, p. 827). It seems obvious that the test might have shown more validity - which proved to be zero - if it has been administered at the beginning of the testing period.

Studies of Deterioration in the Performance of Tasks Simulating Flight.

Bartlett, reviewing extensive studies of 'fatigue' made after the first World War, many of which were done under his sponsorship at Cambridge, or with his collaboration (Wyatt and Weston 1920; Muscio 1922; Vernon 1926; Pollock 1929; Wyatt and Langdon 1927), concluded that "the skill fatigue of daily life is not set up under these conditions"; i.e. by requiring subjects to repeat over and over again easy calculations, word and color recognition or other disjunctive tests. "Routine repetition of simple actions is not a characteristic of any highly skilled act, and least of all of work having a strong 'mental' component. The operations involved are marked by complex, coordinated and accurately timed activities" (1943, p. 247). Acting on this hypothesis, Bartlett initiated a series of studies aimed at analyzing disorganization of the skilled

activities involved in piloting a plane (the Cambridge Cockpit studies: Craik 1940; Drew 1942; Bartlett 1943; 1947; and Davis, 1946a, 1946b, 1947, 1948).

An important feature of the set-up in the Cockpit was the arrangement of the pointers and light sources on the panal board. The signals were arranged in three chief groups: in the middle, a group important throughout the whole period of the test; at one side, a group important only at certain stages, especially at the beginning and the end; to the other side, a group intermittently important indicating occurrences calling for prompt, but only occasional action. Above and below were stimuli which could be brought in at the experimenter's will, calling for a specific response, less specifically bound up with the central task.

Subjects for the test were trained pilots, the numbers in the different studies ranging from 34 to 355. They were given written instructions for four maneuvers, together occupying ten minutes, to be repeated between intervals of straight, level flying, the whole test usually taking two hours, with one test lasting four hours. In the course of a 2-hour run there was a progressive deterioration which amounted to 92 per cent in speed control, an increase of as much as 400 per cent in the proportion of 'large errors' over 'small ones' in side-slip. There was a decrease in accuracy of timing, the estimates being, at times, as much as 200 per cent in error. Deviations in the side-slip pointer increased from two or three to ten degrees, and finally swung from side to side over a wide range before anything was done. These measurements have less than one chance in a hundred of being accidental.

A limitation of tests as complicated as those made with the Cambridge Cockpit is the difficulty of quantification of results. Results which appear to have considerable significance, however, are reported in qualitative terms. As the test proceeded, the panel, which at first was perceived as an integrated whole, to quote Bartlett (1943, p. 252) "split up, so that it became twenty or so separate recording instruments. And the controlling movements split up also, so that when any one was made it was not pictured in a pattern of machine control, but only as the correction of a particular instrument reading". There tended to be a regular sequence in deterioration of response to the display panel. The splitting of the stimulus field proceeded regularly from margin to center. "The merely occasional stimuli were the first to break away from the rest. There was a phase during which they were met by delayed, and often hurried, response. At length they were very frequently indeed ignored, to use psychological language they were 'forgotten', and there was a definite and, as it might be called, 'stupid' lapse of attention." For example, "with increasing fatigue, over and over the petrol signal was ignored, until the machine stopped and the experiment reached a temporary inglorious end" (pp. 252-253).

With many subjects there was demonstrated a progressive tendency toward a lowering of the standard of performance without his awareness of the fact. More difficult instructions being introduced, some subjects improved quickly and the improvement was maintained for a long time. There were others, however, who improved but temporarily, soon slipping back to a lower level than before.

Pilots complained of 'stickiness of attention', i.e., of preoccupation with one particular maneuver, other things being unduly neglected. For example, while gaining height accurately according to instructions the machine might be allowed to drift off-course. When the climb was completed, the deviation off-course would then be rapidly, often violently, corrected. This erratic tendency could be noticed and picked out from the graphic records. This effect is closely allied to, if not a part of, the more inclusive factor of poor timing. In fact, increasing inaccuracy of the timing response is one of the outstanding features of deterioration in performance. Inasmuch as the timing of the different elements in a complicated response is subject to objective measurement, it may provide a promising lead to follow in future experimentation.

Some pilots also made "apparently unreasonable and stupid mistakes", which are described as 'lapses'. These are exemplified by such performances as making the machine climb the number of feet it should have dived, or completely omitting a particular maneuver.

On the basis of performance an attempt was made to differentiate normal and non-normal pilots, the latter group being further divided into an 'overactive' type (those whose total number of movements of the controls was high relative to duration of errors) and an 'inert' type (those for whom the total number of errors is high in relation to the total number of movements). The former are alleged to be 'hyperemotional', while the latter are characterized as "bored, distracted, and emotionally indifferent". A relation to operational fatigue is suggested by the tendency for the same effects to appear in normal pilots as a result of long periods of performance in the apparatus. Further, poorer scores are reported to occur disproportionately in a group of 'operationally fatigued' pilots. Validity for the Cockpit test has, in some measure, been established by a demonstrated correlation between scores and accident proneness within a small group of pilots.

The authors of the test acknowledge its limitations: the relatively long time required for administration, and limitation to relatively experienced pilots. The approach to problems of performance represented in these studies emphasizes the subject's generalized modes of attack on his tasks and problems rather than his specific skills.

Studies of Operational Fatigue.

In the various attempts made by aviation psychologists to find among returned aviators factors of personality related to operational fatigue and anxiety, use was made of a variety of measures (Wickert 1947; Bijou 1947; Lepley 1947). It was discovered that tests that had been developed primarily as measures of intellectual, perceptual, and motor factors associated with success in flight training offered no promise of also predicting susceptibility to emotional disturbance after combat. (Wickert 1947). Of special interest were the Aiming Stress, and Steadiness under Pressure tests, which had been definitely designed to measure resistance to verbally induced emotional responses. These, however, proved to be of no value in predicting the anxiety reaction after combat.

Two types of personality assays were administered for the purpose of comparing the characteristics of normal returnees with those with anxiety reactions: (1) Instructor-Selection Tests, and (2) Inventories of Personal Characteristics. The Instructor-Selection Test, planned as an indirect method of determining certain personal characteristics did not differentiate between a group of 93 anxiety cases and 576 controls at AAF Redistribution Station, No. 1, but it was found discriminatory at the 2-per cent level in contrasting 227 anxiety cases with 300 controls, at Redistribution Station, No. 2.

After successive item analyses a form of Personality Inventory (DE201C) was evolved which had an odd-even reliability of .768 (corrected), and a validity of the order of .50 with the diagnosis of anxiety reaction (Wickert 1947). The items of this inventory confirm the picture of anxiety reaction as one of nervousness, poor sleep, disturbing dreams, fatigue, and somatic evidences of emotion. Significant items suggest the role of combat strain as an antecedent of anxiety reaction, or at least as a precipitating factor. Fear, loss of weight, and loss of zest for flying are highly significant features.

A Sociological Questionnaire indicated that length of service overseas discriminated between the mild anxiety reaction patients and the more severe groups at the 1-per cent level of confidence. The more severe groups had spent 2.75 more months overseas than had the mild group. The patients discharged to civilian life because of the severity of their condition had averaged 3.3 months longer overseas than had those patients returned to duty. This difference was also significant at the 1-per cent level of confidence. Presumptively traumatic factors (e.g., crashes, death of companions, parachute jumps) were adjudged to be so subjectively conditioned as to be impossible of definition in such fashion as to give them uniform meaning in a questionnaire or check list.

An analysis of the attitudes of combat flyers who were returned for reassignment in this country during 1944 and 1945, with reference to a second tour of aerial combat duty, however, showed that there was no consistent relationship toward a second combat tour and the statistics of the first tour expressed as number of combat hours, number of missions, or number of months overseas. "This leads to the most significant conclusion of the study when compared with the data on fear. How the man reacts psychologically to combat determines his attitude. The numerical count of hours, missions, and the like, does not" (Wickert, 1947, pp. 171-172). Both officers and men who had spent 12 or more months overseas were slightly more favorable toward return overseas than those who had been in the theater for a shorter time.

The questionnaire employed by Grinker et al (1946) was found to be an unsatisfactory device for differentiating air crew personnel returned to this country with 'operational fatigue' from control groups. One study was made of 284 officers, another of 198 enlisted personnel. The questionnaire contained 121 items, dealing with the patient's precombat personality and with his behavior during combat. The conclusion drawn from this investigation is that more drastic screening on the basis of predisposition to combat fatigue would be bought only at the cost of a higher rejection of candidates who are fit. Moreover, 'predisposition' is only one cause of war neurosis. Among other factors are the type of stress to which the individual is exposed and the combat unit's morale.

Most of the studies in which projective techniques have been employed with subjects exposed to vigil or operational fatigue have given negative results. As mentioned earlier, Tyler (1947) found no alternations in the Rorschach responses after as much as 112 hours of sleep deprivation. In a study made at an AAF Convalescent Hospital (Bijou 1947), the records made by the patients were very similar to those made by the aviation student group used as a control sample, the records having been made while they were in the process of qualifying for aircrew training. Harrower and Grinker (1946) devised a "Stress Tolerance Test", which was administered at another of the AAF hospitals. A set of pictures of war scenes was sandwiched between a sample of ink-blots and TAT pictures. It is reported that patients suffering from operational fatigue were so greatly 'disturbed' by the war scenes that they made a significant percentage of failures to respond at all, or they 'personalized' their responses to the second set of projective stimuli. Results obtained with the Bender Visual Motor Gestalt Test (which requires the subject to copy geometric designs) were inconclusive (Bijou 1947). An Incomplete Sentence Test (DE303A, Bijou 1947), requiring the subject to complete a sentence which has been started, gave some indication of validity as a means of differentiating groups of patients judged by psychiatrists to be fit for duty from those judged to have moderate or severe adjustment

problems as a result of their war experiences. The reliability of the test by one method was "above 0.85", by another method, 0.68.

A very important qualitative factor, according to the testimony of Flight Surgeons, contributing to operational fatigue consists of such events as disrupt the esprit de corps of the crew and the squadron. The disorganization of the skill of an individual member of a crew is apparently as apt to result from a catastrophy experienced by some other member of the crew as from the physical conditions encountered during flight. This fact has been reported for all branches of the armed services (Wright 1945, 1946; Bartemeier et al 1946). Wright claims that the most universal motivating forces are those generated by the relationship of the man to his group. This conclusion is supported by the observation that when an Air Force is small, replacements few, losses and opposition severe, men have continued to fly well. When, on the other hand, the Air Force has grown large, is packed with replacements, and is suffering only occasional losses and opposition, men have much more frequently 'broken down'. A similar position is expressed by Bartemeier, Kubie, Menninger, Romano and Whitehorn (1946): "When one considers the total pattern of defenses which are utilized by the soldier in combat, it appears that the most significant factor is the soldier's position in the constellation of his social group, the combat team..... Further confirmation of the importance of these group bonds appears in the nature of the precipitating factors in the 'break'. The common denominator of the events experienced by the soldiers and related by them as precipitating factors were less frequently the 'last straw' in a quantitative sense than some event which necessitated a sudden change in the basic structure of the pattern of the soldier's group relationship....The soldier lost his group relationship and in losing it forfeited all the strengths and comforts with which it had sustained him. As a member of the team he would have been able to carry on; alone, he was overwhelmed and became disorganized".

SUMMARY AND INTERPRETATION OF THE STUDIES OF FATIGUE, APPREHENSION AND STRESS

Perusal of the studies of tests taken after loss of sleep, or long periods of work, indicates that any possible 'fatigue' that may have resulted is not readily detected by short, discrete tests. In cases such as illustrated by ten hours or more of truck-driving, involving continued postural strain in the trunk and arms, however, subsequent testing reveals a decrement in such tasks as involve postural and manual control (body sway, tapping time, manual steadiness and coordination). In situations of this sort one is probably measuring some of the functions that have been impaired by the day's work. But even with tests that are continued for hours there may not be significant decrement. This might be expected to be true of tasks that are readily automatized, like tapping, but reference to

automatization will not explain the case of reading the works of Adam Smith (Carmichael and Dearborn 1947).

Several experimenters suggest that in tasks requiring constant attention the 'fatigue' and deterioration in performance are due to tension, anticipatory or concurrent (Mackworth 1948a, Davis 1946, 1948). Bartley and Chute have concluded that fatigue, "rather than being looked upon as some sort of physiological impairment, should be regarded as the pattern arising in a conflict situation" (1945, p. 169). Eye strain is a familiar example of tension commonly recognized as fatiguing. Bartley and Chute describe a situation in which conflict is set up involving the pupillary light reflex. "Slow changes in level of illumination elicit changes in the size of the pupillary aperture by means of the reciprocal action of the opposing muscles. One set of muscles upon contracting dilates the aperture, and the contraction of the other set constricts it. If alternations from light to dark are rapid enough, both sets of muscles may come to contract simultaneously and a clear cut and simple example of incompatibility occurs" (1947, p. 218). Bartley cites another experiment in which conflict is set up between voluntary fixation and the reflex tendency to respond to a specific light source (Bartley 1942). Lights are set up 30 degrees to either side of the line of regard and the subject is instructed to focus an intermediate band, thus introducing incompatibility between the normal reciprocal innervation of the extrinsic muscles, involved in the reflex process of focusing one or the other of the lights, on the one hand, and contractions required to focus the intermediate band, on the other. The ensuing tension is readily appreciated.

It is presumably correct to say that when a person is adequately motivated he is free from debilitating tension, frustration, or conflict. On the other hand, one does not 'do his best' except when under the emotional reinforcement of the 'right sort' of tension. The problem is to discriminate between facilitating and decremental tensions. Davis (1946a, 1946b, 1948) attributes the deterioration that occurred in the tests with the Cockpit to 'anticipatory tension'.

Of the objective evidence furnished by the Cambridge studies a factor which merits special emphasis is the disruption in the timing of the performance. As Bartlett says, timing is of little significance in relation to single reactions, but when a single reaction must be fitted into a complex pattern it becomes of paramount importance. With mounting tension it is the timing that goes wrong rather than the efficiency of the local reactions. It is then that the rhythm of sequence in the complex activity is lost; the performance becomes irregular, "a story of spurts and delays" (Bartlett, 1943, p. 255). This conclusion as to the importance of correct timing is supported by an experiment with Landolt rings (broken circles with the gap north, south, east, or west, in relation to the observer (Markstein 1932). The time and duration of appearance of each item in the display

are automatically recorded, and similarly the beginning and end of every reaction and of the intervening intervals. In the analysis of deterioration in a subject's reactions to the successive presentation of the rings it is observed that when the subject breaks down he is, in almost all cases, trying to respond, not to the circle that is immediately before him, but to the preceding circle, or to the second or third preceding circle. Bartlett reports that there is some evidence that much the same happens in tracking a rapidly moving target, and in dealing with radar displays in extremely rapid sequence (Bartlett 1947). In these instances it would appear that the receptor and effector series have got out of step. He cites the case of reading, in which the eye interprets far ahead of the voice, and those skills in which the posture has to be reset. "For then it is the accessory movements, of which normally the operator remains totally unconscious, which markedly and obviously go wrong. The footwork, which may settle the whole body balance, lags and sets everything else out of time." (Bartlett 1948, p. 36)

Analysis of the disruption of correct timing is directly related to the splitting of the stimulus field which was found to occur in the Cockpit studies. As reported earlier, as the task continued the stimulating panel, which was, at first perceived as a pattern, split up into twenty or so separate instruments. There was a corresponding splitting up of the controlling movements. As a rule the splitting occurred regularly from margin to center. The occasional stimuli were met with delayed, and often hurried, responses; at length they tended to be completely ignored.

Another observation to be drawn from the Cockpit studies, more difficult to quantify, is the phenomenon of "lowered standard". As Bartlett says: "....within the skill there are always two (discrimination) thresholds- one a measure of what the observer <u>can</u> do, and the other of what is treated as <u>worth</u> doing. These can, and constantly do, vary quite independently. At the beginning of exercise they normally approximate to the same value though they are never quite identical. With continued exercise, or under a variety of other conditions, they diverge more and more. The threshold of discrimination - what the operator <u>can</u> do - is little affected, except in extreme cases; the threshold of indifference - what is treated as <u>worth</u> doing - may rise to double, treble, or quadruple its original value.... The operator may know nothing about it. He may assert that his skill is exactly as it was, and if he is stopped and his threshold of discrimination measured he may appear to be right. For a genuine measure of his skill he needs to have both these thresholds determined within the operation itself" (Bartlett 1948, p. 38).

Two generalizations may now be made in concluding this section of the report. In the first place, when it comes to constructing tests to measure the process of deterioration in the performance of a skilled task one may well recognize as a basic generalization the configurationist's dictum: the whole is something more than a sum of the parts. Measurement of decrement in isolated reactions throws

little light upon deterioration in a complex skill, even though, as Section I shows, many isolated reactions are sensitive to decrement. Techniques of measurement must be employed which will record what is happening simultaneously, as well as successively, in the complete sensory-motor pattern. Bartlett's emphasis upon the importance of accurate timing of the constituent elements suggests a method of approach which should prove highly fruitful.

A second basic consideration lies in the all important area of motivation. It has long been recognized that the problems of fatigue in aviation are psychological. Grow (1936) stated that the true cause of fatigue, rather than being muscular exertion, is to be found in "instinctive and premature fear". McFarland concluded: "Although one can demonstrate that certain muscles are subject to loss of efficiency in ergographic studies, this sheds little light on the fatigue problem in aviation, in which the pilot's musculature is not used excessively..... The emphasis has been placed upon psychological factors, such as worry and mental and emotional conflict" (1941a, pp. 4 and 12).

One reason why inconsistent results have so often been obtained in the attempts to measure the effects of fatigue is that the motivating conditions have not been comparable. In spite of the fact that job sampling has definite limitations as a method for studying deterioration in skill, it does have the advantage of providing motivation comparable to that in which the task itself is performed. One great difficulty of most of the tests that have been used to measure fatigue is that the activation has been artificial. Tests that will effectively measure deterioration in the skills of aviation need to be administered under tensions and aspirations comparable to those under which those skills actually function professionally. The tests will need to measure not only what the subject is capable of doing but what he considers worth doing, the relationship between his level of aspiration and his threshold of ability, under the stress of tension-producing circumstances.

APPENDIX

A-1. Tests of Visual Function.

For purposes of this report tests of visual function include measures of visual acuity, brightness discrimination, dark adaptation, area of visual field, area of blind spot, accommodation, depth perception, and of other functions involving what is commonly accepted as the purely 'receptive' function of the eyes. These tests cannot be entirely overlooked in a study of the present sort since a majority of major investigations of performance under various deleterious conditions have included one or more tests of visual reception in the battery used. In so far as some of the tests listed may be employed as indices of psychological functions other than purely sensory, they are of interest. Also they are of importance in many studies as controls on the possibility that apparent deficit in more complex processes is actually due to deficiency in the visual process, per se. To subserve these purposes a representative list of visual tests has been appended as Table A-1, although, because of the diversity of tests employed, results are not tabulated. Investigations employing visual tests to detect behavioral inefficiency under anoxic conditions will be seen from Table A-1 to be especially numerous.

A-2. Critical Flicker Frequency Tests.

Among the tests of visual function those dealing with critical frequency of flicker fusion are singled out for special attention both because of the bulk of work that has been done with them, and, in addition, because they make apparent the logic of much of the research effort in the general area under discussion. The relatively great amount of emphasis given to the test seems to stem, in part, from an interest in finding an involuntary response, which is presumably less sensitive to learning than voluntary responses, and which, consequently, cannot be compensated for to any great extent by voluntary effort. In addition, C.F.F. tests offer the possibility of providing an objective yardstick which would be closely related to changes in the environmental variable (e.g. hours of fatiguing activity) and/or with subjective reports of 'fatigue' against which other measures of psychological performance might be validated.

The minimum frequency per unit time of a given illumination which just results in the report of fusion, rather than discrete flashing, by an observer, is conventionally known as the critical flicker limen. A large amount of work done on this phenomenon has shown that the flicker fusion threshold varies with a number of factors such as brightness of illumination, color, size of test area, and the like. Several methods have been used to test this function. The newer techniques substitute an electronic apparatus with a neon-glow lamp for the older motor driven disc apparatus. Descriptions of standard

Table A-1

TESTS OF VISUAL FUNCTION[1]

(Results not listed because of variety of tests used)

A. Altitude and related conditions.	Year	Test
Bagby	1921	Visual acuity
Gellhorn and Spiesman	1935	After-images.
Gellhorn	1936 a	Visual discrimination
Gellhorn	1936 b	Visual discrimination
McFarland	1937-I	(Various)
McFarland	1937-II	"
McFarland & Edwards	1937	"
McFarland	1938	"
Evans & McFarland	1938	Central visual field
Ferree and Rand	1938	Multiple exposure tachistoscope
McFarland and Evans	1939	Dark adaptation
McFarland, Evans & Halperin	1941	Review
Berger et al	1943	Visual resolving power
Barach, Brookes et al	1943 a	Angioscotoma
Chapanis, A.	1943 a	Visual acuity (Luckeish-Moss)
"	1943 b	" " " "
Pinson	1943	(Luckiesh-Moss) acuity
Pinson, Chapanis & Rouse	1943	Contrast sensitivity
McFarland, Hurvich & Halperin	1943	After-images
Chapanis, A.	1944 a	Visual fields
"	1944 b	Night vision
McFarland, Halperin & Niven	1944	Visual thresholds
McFarland, Roughton et al	1944	" "
Halstead	1945	Dynamic visual field
McFarland, Halperin & Niven	1945	Visual thresholds
Eckman, Barach et al	1945	Hecht Visual discrimination
Green et al	1945	Peripheral visual field
King et al	1945	Angioscotoma
Chapanis, A.	1946	(Luckiesh-Moss) acuity
McFarland, Halperin & Niven	1946	Visual thresholds
Birren, Fisher et al	1946	"Red color field"
Vollmer et al	1946	" " "

[1]No attempt was made to cover this field. The list is exemplary only.

Table A-1 (con.)

	Year	Test
A. Altitude and related conditions (con.)		
Otis, Rahn et al	1946	Hecht contrast discrimination
Rahn, Otis et al	1946	" " "
Smith, Clark & Seitz	1946	Angioscotoma
Green	1947	Peripheral visual field
Smith, G. M.	1948	Angioscotoma
B. Fatigue conditions.		
McFarland, Holway & Hurvich	1932	Fatigue
Cooperman, Mullin & Kleitman	1934	Visual acuity (sleep privation - 60 hrs.)
Katz and Landis	1935	" " (" " - 10 days)
Ryan and Warner	1936	(Various) (Hours of driving)
Edwards	1941	(Various)(sleep privation - 100 hrs.)
Jones et al	1941	(Various) (Hours of driving)
Tyler	1947	(Various)
Bartley	1947	Review
Brozek, Simonson and	1947	(Various) (Visual work test)
C. Dietary modification.		
Keys et al	1945	(Various)
Simonson, Brozek & Keys	1948	(Various)
D. Noise and Vibration.		
Coermann	1939	(Various) (Both note decrement
Stevens	1941	" in acuity)
E. Carbon monoxide.		
Forbes, Dill et al	1937	(Various)
McFarland, Roughton et al	1944	Thresholds
Vollmer et al	1946	"Red color field"
McFarland	1946	(Various) additional effects of smoking

Table A-1 (con.)

	Year	Test
F. Alcohol.		
Miles	1924	Visual acuity (Ives)
Jellinek and McFarland	1940	Review
G. High CO_2, decreased O_2 in sealed chambers.		
Consolazio et al	1947	Dark adapted form-acuity (o)
H. Review of perceptual problems.		
Fernberger et al	1941	Various)

methods and techniques will be found in Jones et al (1941), Draeger and Fauley (1943), Henry (1942), and Misiak (1947).

C.F.F. Tests have been used by several investigators under conditions of simulated altitude with results consistently showing a decrement. (Seitz 1940; Lilienthal and Fugitt 1945; Vollmer et al 1946; Birren et al 1946). Under fatigue and allied conditions the results have been less conclusive: two studies (Simonson and Enzer 1941; Jones et al 1941) show decrements, while two others yield none (Tyler 1947; Brozek and Keys 1944). Excessive CO_2 and oxygen dimunition had no effect on C.F.F. Findings under other conditions are summarized in the accompanying Table A-2.

The reliability of a test of the present type has been reported by Misiak to be high (.93, test-retest, 3rd with 10th day). However, the fact that the reliability was low when the scores obtained on the 1st and 10th days were compared, suggests a fairly strong initial habituation, or practice effect.

A-3. Tests of Auditory Function.

Tests of auditory acuity, pitch discrimination, as well as of other functions involving the ear, have been employed in the measurement of performance decrement. References cited provide, in view of the purpose of the present survey, only a sample of work in this field. For the most part, little decrement in simple auditory function has been reported under conditions studied. However, it appears to be fairly well founded that intelligibility of speech is diminished (McFarland 1946) at altitude, and Van Liere (1942), in a review article containing an extensive bibliography of the subject, has reported some decrement in response to auditory stimulation, depending, apparently, on degree of anoxia and length of exposure.

A-4. Tests of Other Sensory Functions.

Reasons that determined a minimum consideration of vision and audition are applicable to the remaining sensory fields. References cited are representative of techniques employed to detect sensory deficit under the conditions listed.

A-5. Measures of Physiological Correlates.

The accompanying Table is based on a residium of references not included in the body of the paper since the problem of physiological concomitants of performance was deemed to fall outside of the present study. With few exceptions, results obtained

Table A-2

CRITICAL FUSION FREQUENCY OF FLICKER

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Seitz	1940	Altitude (17,500 - 20,000 ft.)	4	(-)	No immediate recovery on return to air.
Simonson and Enzer	1941	Working day	19	(-)	Decrement parallel to subjective fatigue.
Jones et al	1941	Hours of driving	528 truck drivers	(-)	Slight but consistent.
Graybiel et al	1943	Daily flying schedule	32 Naval aviators	(o)	
Lilienthal and Fugitt	1945	Altitude (9,000 to 12,000 ft.)	5	(-)	
		(5,000 - 6,000 ft.)	5	(o)	
		(5,000 - 6,000 ft.) + CO	5	(-)	
Keys et al	1943 1944 1945	Diets restricted in B-complex vitamins -184 days.	8	(o)	
Brozek and Keys	1944	Normal	12 trained 56 untrained		Test-retest satisfactory.
		Normal - practice 15 days	8	(o)	
		Exercise - 1 hr. 4 hr.	14	(o)	
		Heat and work	6	(?)(-) (?)(-)	Slight.

Table A-2 (con.)

CRITICAL FUSION FREQUENCY OF FLICKER

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Vollmer et al	1946	Altitude (10,000 - 15,000)	17	(-)	
		Altitude + CO (10,000 ft.)		(-)	But no greater than with altitude alone.
Birren et al	1946	Altitude (10,000 ft.) (14,000 ft.) (15,500 ft.) (18,000 ft.)	29	(-)	Progressive with degree of anoxia.
Keeton et al Glickman et al Mitchell et al	1946 1946 1946	Diet - Cold ($-20^{o}F$) and Clothing	12	(-)	In cold. Effects of diet and clothing in preventing decrement difficult to follow.
Consolazio et al	1947	CO_2 excess - O_2 decrease in sealed chambers	77	(o)	
Krugman	1947	Operational fatigue	50-normal 50-operational fatigue		
Tyler	1947	Sleep privation (up to 112 hrs.) Barbiturates	488	(o)	
Misiak	1947	Normal	100 Male and Female	(o) (-)	Sex. Age.
Misiak	1948	Normal 10 tests over 8 weeks	6		r(test-retest)= .189 (1st with 10th) r(test-retest)= .933 (3rd with 10th) omitting 1st 2 days tests, r = satisfactory and consistent.
Simonson, Brozek and Keys	1948	Controlled work task -diet	6 young men		

Table A-3

TESTS OF AUDITORY FUNCTION

Source	Year	Condition
Patrick and Gilbert	1896	Sleep privation
Bagby	1921	Anoxia
Kleitman	1923	Sleep privation
Gellhorn and Spiesman	1935	Anoxia
Katz and Landis	1935	Sleep privation
McFarland and Forbes	1936	Altitude and alcohol
McFarland	1937-I	Altitude
"	-II	"
"	-IV	"
"	(other articles and books)	
McFarland, Graybiel et al	1939	Altitude
Coermann	1939	Vibration
Stevens, S. S.	1941	Noise and vibration
Burris-Meyers et al	1942	Noise
Tufts College Fatigue Studies	1942	Sleep privation
Lewis, D.	1943	Noise and vibration
Smith, G. M.[1]	1946	Altitude
Smith and Seitz[1]	1946	"
Smith, G. M.	1948	"
Tyler, D. B.	1947	Sleep privation
Consolazio et al	1947	High CO_2, decreased O_2

[1] Speech intelligibility. A large war literature is available on this subject which was considered beyond the scope of this report. A brief review can be found in McFarland (1946) p. 288.

Table A-4

TESTS OF OTHER SENSORY FUNCTIONS

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Cutaneous sensitivity.			
		1. Tuning Fork sensitivity (vibration sense).			
Tyler	1947	Wakefulness (24 - 114 hrs.)	65	(o)	
		Benzedrine		(o)	
		Barbiturates		(o)	
		2. Threshold for electric shock.			
Miles	1924	Alcohol		(-)	
Lee and Kleitman	1923	Wakefulness (up to 112 hrs.)	1	(o)	
		3. Threshold of sensitivity to touch and pain.			
Cooperman, Mullin and Kleitman	1934	Sleep privation (60 hrs.)	6	(-)(?)	Some change in sensitivity
Mullin and Luckhardt	1934	Alcohol	10		
		-touch		(o)	
		-pain		(-)	Decreased sensitivity to pain.
		4. Perception of tilt.			
Henmon	1919	Normal	300		
Stratton et al	1920	Normal	Cadets and instructors		
McFarland and Franzen	1943	Normal	Naval aviators		Test difficult to use.
Lewis, D.	1943	Noise and vibration	80	(o)	

Table A-4 (con.)

TESTS OF OTHER SENSORY FUNCTIONS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		5. Perception of acceleratory rotary motion.			
Travis	1944	Description of apparatus. Normal - with and without visual cues	100 Male 99 Female		Wide variability of scores. Individual subjects worse without visual cues.
		6. Perception of vertical movement.			
Gurnee	1934	Apparatus description - teeter-board			
		Normal	3		Thresholds, variability, judgment of extent.
		7. Perception of vibration.			
Meister	1935	Vibrations - different intensities and duration	15		Thresholds of perception, - discomfort, and injury.

with these measures under the conditions indicated have failed to demonstrate any clear cut relation either to performance or to a criterion useful for selection. The list of tests is believed to sample the field of studies of the type under consideration, but may not be considered exhaustive.

A-6. Tests of Eye-Movement and Frequency of Blinking.

Since ocular-motor functions have been demonstrated to be influenced by several environmental conditions, brief mention is made of the tests that have been used to measure them. Eye-movements are usually recorded by either of two methods: (1) by means of an ophthalmograph which is essentially a camera with dual lenses designed to record images reflected from the two corneas on a continuously moving strip of film; and (2) by means of electrical apparatus which indicates changes in the corneo-retinal potential as this is determined by movements of eyes in their orbits. For a description of tests of the present type, apparatus and techniques, the interested reader is referred to the work of Jones et al (1941) and that of Hoffman, Wellman and Carmichael (1939).

Impaired control of saccadic eye movements has been reported under several of the conditions listed, including altitude. For a discussion of reliability of the ophthalmographic method, generally reported as high, the work of Tinker (1936) is cited. McFarland and his collaborators (1937) call attention to the test as one especially sensitive to altitude, and further, as one that may be presumed to be uninfluenced by 'compensation' since the subject is unaware of impairment.

Frequency of blinking movements of the eye-lid are recorded by the same methods described above for eye-movements. Luckiesh and Moss (1937) have offered evidence showing that rate of blinking is a positive function of the duration of a visual task, and is therefore an index of visual fatigue. However, Bitterman and his collaborators (1945, 1946, 1947) have failed to confirm the findings of Luckiesh and Moss. Carpenter (1948) has reopened the present issue by showing a marked rise in rate of blinking during the first to the second half hour's performance on the 'clock test' previously described.

A-7. Strength of Grip Tests.

The references listed in Table A-7, while they neither exhaust the varieties of the test, nor the applications to which they have been put, are believed to be representative of work in the present field. In the most frequently used test of strength, the hand grip is measured by instructing the subject to raise a dynamometer gripped

Table A-5

PHYSIOLOGICAL CORRELATES

Source	Year	Condition
A. General references.		
Wenger	1942	Normal
McFarland and Franzen	1943	"
Melton	1947	"
B. Salivary output and pH.		
Winsor and Strongin	1933	Caffeine
Winsor and Richards	1935	Smoking
C. Vascular skin reaction.		
Ryan and Warner	1936	Hours of driving
Jones et al	1941	" " "
D. Blood pressure, pulse rate, heart period, etc.		
Scott, J. C.	1930	Emotion
Armstrong, H. G.	1938	"
Kirsch	1945	Combat
Ellis, F. P.	1947	Heat and exercise
Innumerable data throughout bibliography.		
E. Respiration and energy metabolism.		
Totten	1925	Emotion
Lewis, D.	1943	Noise
Corey	1948	Flight
F. Body temperature.		
Kleitman	(Series)	Sleep and diurnal change
Fahnestock	1946	Measurement in flight
Ellis, F. P.	1947	Heat - Naval problems

Table A-5 (con.)

PHYSIOLOGICAL CORRELATES

Source	Year	Condition
G. Electroencephalography.		
Lewis, D.	1943	Noise
Tyler et al	1947	Sleep privation (24 - 114 hrs.)
H. Electric skin resistance.		
Davis , R. C.	1932	Noise
Ruckmick	1940	Fatigue
Freeman	1940 a	Frustration
Lovell and Morgan	1942	Sound
I. Muscular tension.		
Freeman	1932	Sleep privation
Freeman	1935	Diurnal
Block	1936	Performance
Freeman	1939	Distraction
Freeman	1940	Performance
Stevens	1941	Noise
Davis , D. R.	1942	Methods of measuring
Courts	1942	Review - relation to performance
Williams et al	1946	Pilot performance
Kennedy and Travis	1947 a	Alertness
Travis and Kennedy	1947	Alertness
Kennedy and Travis	1947 b	Speed of performance
Davis and Van Liere	1949	Gunfire startle
J. Motility during sleep.		
Geldard	1944	Normal - pilots
Kleitman	(Series)	Normal and post-insomnia
Mackworth	1948 a	Heat

Table A-6

EYE MOVEMENTS AND FREQUENCY OF BLINKING

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		A. Eye movements.			
Tinker Tinker	1931 1936	During reading			Apparatus, reliability and validity.
Miles	1924	Alcohol	Varied)	(-)	
Miles and Laslett	1931	Sleep privation (66 hrs.)	5	(-)	30% slower than average.
McFarland, Knehr and Berens	1937	Altitude (18,000 ft.)		(-)	
Clark and Warren	1940	65-hr. vigil	3	(?)(+)	Greater effort required.
Stevens, S. S.	1941(a) 1941(b)	Noise (90 and 115 db.)	5	(o)	
Jones et al	1941	Hours of driving since sleep	528 truck drivers	(-)	For those who had driven at all. No progressive decrease with hours.
Hoffman	1946	Visual fatigue (reading 4 hrs.)	30		
Carmichael and Dearborn	1947	Visual fatigue	40	(o)	
		B. Rate of blinking.			
Luckiesh and Moss " " " Luckiesh Bitterman Bitterman and Soloway Bitterman	1937 1940 1947 1945 1946 1947	Series of articles on the relation of rate of blinking to visual fatigue.			
Carpenter	1948	Prolonged visual search for 2 hrs.	20	(-)	Increase in blinking by 43%.

in the hand, to the level of the head, then to bring it down quickly, exerting maximal pressure. Three tests are given with each hand alternately, and the best three counted as the score. Other tests similar in principle have been designed to measure strength of the back and legs. For descriptions of standard Smedley apparatus and technique reference is made to Whipple (1914), Garrett and Schneck (1933), Gray and Trowbridge (1942). Fisher and Birren (1946) describe a modified apparatus, calibrated on a different scale, together with an improved way of administering the test.

Results obtained under a wide variety of conditions show preponderantly negative results on strength of grip tests. Decrements are reported under the conditions of cold (Horvath and Freedman 1947) and heat (although the test used under the latter condition is more one of physical endurance than strength) (Mackworth 1947), and following a 'fatigue run' (Fisher and Birren 1946). Improved performance on a dynamometric test has been demonstrated with the administration of benzedrine (Thornton, Holck, and Smith 1939). Other conditions, including drugs, diet, toxic fumes, and fatigue, resulted in no impairment in strength, or were indeterminate.

The reliability of a test of the present type is reported by Fisher and Birren (1946) to be high, achieving split-half values of .91 - .92 (corrected). Test scores are reported by the same investigators to be somewhat influenced by practice.

Evidence is lacking to show that strength of grip is an index of any psychological function or, in fact, that it represents anything more than the strength of the bodily member tested. The work of Keys et al (1941, 1944, 1945) and of Brozek et al (1946) justifies the conclusion that such tests are remarkably resistant, even to extreme conditions of deficiency. Intercorrelations of dynamometric test results with those obtained with psychomotor tests have been uniformly reported to be low or zero.

A-8. Tests of General Intelligence.

In spite of the widespread employment of tests of general intelligence in the detection of deficit in performance, there appear to be several reasons for devoting a minimum of consideration to them in the present treatment. Foremost, as will be seen from the accompanying table, the outcome of a majority of these efforts has been negative. Almost of equal importance is the fact that intelligence testing has been exclusively concerned with the problem of predicting success and failure in highly specific and complex life situations rather than with the separate task of

Table A-7

TESTS OF STRENGTH OF GRIP (HAND DYNAMOMETER)

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Patrick and Gilbert	1896	Sleep privation(90 hrs.)	3	(o)	
Stratton et al	1920	Normal	50-70 aviators	(o)	No relation to ability to fly.
Johnson, B. J.	1922	Fatigue		(?)	
Dorcus and Weigand	1929	Carbon monoxide	6	(o)	Some increase with practice.
Jersild and Thomas	1931	Adrenaline chloride	6	(?)	Some slight trend of increment.
Katz and Landis	1935	Sleep privation (10 days)	1	(o)	
Husband	1935	Interrupted sleep	1	(o)	
Gilliland and Nelson	1939	Coffee	5	(?)	
Thornton, Holck and Smith	1939	Benzedrine (20 mgm.) Caffeine	3	(+) (?)	 Some increment but not significant.
Jones et al	1941	Hours of driving	650 truckdrivers	(o)	
Edwards, A. S.	1941	Sleep privation (100 hrs.)	19 exper. 10 control	(o)	
Keys et al	1944	Diet - restricted Vit. B complex (40 days)	8	(o)	
Keys et al	1944	Diet - restricted riboflavin (152 days)	6	(o)	

Table A-7 (con.)

TESTS OF STRENGTH OF GRIP (HAND DYNAMOMETER)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Keys et al	1945	Diet - restricted Vit. B-complex (161 days)	8	(o)	Performance remarkably stable during prolonged deficiency.
Brozek et al	1946	Acute deficiency for 23 days	8	(o)	Slight decrease during acute deficiency.
Taylor et al	1945	Fasting - successive 2-1/2 day fasts at intervals of 5 to 6 weeks	4	(o)	
Horvath and Freedman	1947	Cold (-22° F and -10° F)	92	(-)	
Cuthbertson and Knox	1947	Benzedrine or Methedrine	6	(o)	
Fisher and Birren[1]	1946	Standardization	169 Naval personnel 161 Waves 648 Industrial		r(split-half) = .91 - .92 r(test-retest)= .87 (N=72) (2 days)
Fisher and Birren[1]	1946	"Fatigue run"	105	(-)	Significant compared with control test-retest.
Fisher and Birren[1]	1947	Age	552 Male 96 Female workers		Significant relationship between age and score. Maximum in middle 20's, continuous decline thereafter.
Consolazio et al[1]	1947	CO_2 excess, O_2 decrease in sealed chambers	4-77	(?) (-)	In one experiment (17 subjects - for 60 hrs.) but not consistent in other series.

[1]Test standardized by this group involves setting the dynamometer at successively higher levels until the subject fails to reach his goal. This difference in administration may account for the fact that there is some reported decrement in this series, but with none of the other hand dynamometer tests. This test may involve "motivational factors" as well as simple strength.

Table A-7 (con.)

TESTS OF STRENGTH OF GRIP (HAND DYNAMOMETER)

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
		Other strength tests. 1. Strength of back			
Keys et al	1943			(o)	In all the restricted diets
	1944(1)			(o)	and throughout the fasts
	1944(2)	As stated	As stated	(o)	performance remained
	1945	above	above	(o)	remarkably stable and
Brozek et al	1946			(o)	resistant to change.
Taylor et al	1945			(o)	Even during acute deficiency, there was very little decrement.
		2. Pull test (work to exhaustion).[1]			
Mackworth	1947	Hot humid environments (61° to 91° F) E.T.	30	(-)	Greater absolute decrement in "good" performers than in "poor" performers although proportional loss is same.

[1] The "pull test" is not merely a test of strength but more nearly physiological work output. It is included here because it parallels Mackworth's results on other psychological tests.

isolating basic psychological functions of more general interpretability. In addition to offering a coarse mesh with which to measure deficit, intelligence tests are probably too complex to shed much light on the factors being measured.

A number of individual test items or types of items included within tests of intelligence which have been tried out as tests of decrement have been included under other headings (see 'arithmetic computation' and 'logical relations', 'immediate memory', etc.)

In Table A-8 a representative list of general intelligence tests which have been used in measuring deficit is appended. For statements of techniques, materials, reliabilities and interpretations of these tests the reader is referred to the source materials.

Table A-8

TESTS OF GENERAL INTELLIGENCE

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Test	Condition	Subjects	Results: Code	Results: Remarks
Robinson and Richardson-Robinson	1922	Army Alpha	Sleep privation (2 days)	25 exper. 39 control	(o)	
Laird	1925	Reading -comprehension - Thorndike	Diurnal variations	112	(+) (-)	
Lowson	1923	Distorted sentences	Altitude	5	(?)	
Laslett	1928	Thorndike	Sleep reduction	40	(o)	
Cattell, R. B.	1930	Various British forms	Alcohol	50	(+) (-)	10 gm. dose 20 gm. dose
			Caffeine		(-) (-)	0.2 gm. dose 0.4 gm. dose
Husband	1935	Various	Interrupted sleep	1	(o)	
Katz & Landis	1935	Various	Sleep privation (10 days)	1	(o)	
McFarland & Barach	1937	Army Alpha	Altitude	32 psychoneurotic	(-)	In psychoneurotics
				25 normal	(o)	Normal
Kraines	1937	Army Alpha	Anoxia ($10\% \ O_2$)	30	(-)	
Carl and Turner	1939 1940	Various "	Benzedrine	143 38	(+)(?)	Little change
Barmack	1940	Otis	Benzedrine	College students	(o)	
Edwards	1941	ACE	Sleep privation (100 hrs.)	19 exper. 10 control	(-)(?)	

Table A-8 (con.)

TESTS OF GENERAL INTELLIGENCE

Source	Year	Test	Condition	Subjects	Results Code	Results Remarks
Reynolds & Shaffer	1943	Otis	Sulfathiazole	73	(o)	
Flory & Gilbert	1943	Reading-vocabulary	Benzedrine	129	(?)	
Guetzkow & Brozek	1946	Various	Diet- Vit.B deficient	8	(o)	
Glickman et al	1946	Modified Thurstone	Diet - Cold (Vit.B)	12	(o)	Diet Effect of cold not stated
Carpenter, A.	1947	A.H. 4	Heat and humidity	(Not stated)	(o)	
Farnsworth et al	1927	Various	Normal testing	34		No correlation with simple reaction times.
Sisk	1926	Army Alpha	Normal testing	100		No correlation with simple reaction times.
Farmer, Chambers & Kirk and other Farmer, Chambers studies	1933	Linguistic Intelligence	% accident rate	Industrial workers		Part of accident-prone battery.

Table A-9

ASSESSMENT OF PERSONALITY

Source	Year	Condition
A. General references.		
Vernon, P. E.	1938	Survey of field
Ellis, A.	1946	Review of validity
Ellis and Conrad	1948	" " "
B. Bernreuter and personality description blank.		
Carl and Turner	1939	Benzedrine
Turner and Carl	1939	"
Carl and Turner	1940	"
C. Minnesota Multiphasic personality inventory.		
Berryman et al	1947	Vit. B - lack
Brozek, Guetzkow and Keys	1946	Vit. B - deficient diets
D. Free Association.		
Jersild and Thomas	1931	Adrenaline
Gellhorn and Kraines	1936	Anoxia
Gellhorn and Kraines	1937	Anoxia + CO_2
Gellhorn	1937	Anoxia
Bentley	1939	Criticism of Gellhorn's use of test
E. Rorschach (Projective).		
Bigelow	1940	Flying aptitude
Hertzman and Seitz	1942	Altitude
Hertzman et al	1944	Altitude
Tyler	1947	Sleep privation
Brozek, Guetzkow and Keys	1946	Vit. B deficiency
Harrower and Grinker	1946	Validation for "fatigue" and "stress"
F. Cattell's CMS.		
Brozek, Guetzkow and Keys	1946	Vit. B - deficiency
G. Questionnaires, ratings.		
Graybiel et al	1944	Fatigue in pilots
Grinker et al	1946	" " "
Glickman et al	1946	Vit. B.-deficiency
Brozek, Guetzkow and Keys	1946	" " "

Table A-9 (con.)

ASSESSMENT OF PERSONALITY

Source	Year	Condition
G. Questionnaires, ratings (con.)		
Wickert	1947	Comparison of mild and severe anxiety cases.
H. Instructor Selection Test.		
Wickert	1947	Comparison of mild and severe anxiety cases.

Table A-10

SELF-RATING SCALES OF EFFICIENCY OR MOOD UNDER DELETERIOUS CONDITIONS[1]

Code to results:
(-) = decrement; (o) = no change; (+) = increment; (?) = indeterminate

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Armstrong, H. G.	1936	Flying a tactical mission in an open cockpit	35 pilots and observers	(-)	Three critical ranges: $+30^{\circ}$ to $+40^{\circ}$ - clothing -10° - frosting of goggles -20° to 40° - loss of morale, panic, etc.
Vernon and Warner	1932-33	Noise		(-)	Authors consider this the best index of the effects of noise.
Barmack	1937	Interesting work vs. boring work		(?)	
Barmack	1938	2 hrs. boring work	36	(-)	
		Benzedrine		(+)	Retarded development of boredom.
Barmack	1939-I	2-hr. on pursuitmeter	10	(-)	
		Benzedrine		(+)	Retarded rating of boredom.
	1939-II	2-hr. on pursuitmeter	10		
		Lowered temperature		(+)	Report of increased alertness.
		Financial incentive		(+)	Improved rating markedly.
Seitz and Barmack	1940	Altitude (16,000 ft.) Benzedrine	18	(-)	
Carl and Turner	1939	Benzedrine	166	(?)	Appears to be heightening
Turner and Carl	1939	"	166	(?)	of mood, greater optimism
Carl and Turner	1940	"	38	(?)	and interest.

[1]Table includes only those studies where an attempt was made to quantify the rating. Qualitative subjective ratings are to be found throughout the bibliography.

Table A-10 (con.)

SELF-RATING SCALES OF EFFICIENCY OR MOOD UNDER DELETERIOUS CONDITIONS

Source	Year	Condition	Subjects	Results: Code	Results: Remarks
Malmo and Finan	1944	Altitude 12,000 ft. 15,000 ft. 18,000 ft.	12 - mood 24 - liveliness	(-)	Significant at all altitudes. r(test-retest) at 18,000 ft. = .49 for liveliness -.05 for mood.
Brozek, Guetzkow and Keys	1946	Vit. B deficient diet		(?) (-)	Changes - more complaints in unsupplemented group.
Hollingworth	1939	Fatigue due to repetitive work	6	(-)	Used as index of fatigue with which to compare other tests.
Simonson, Brozek and Keys	1948	2-hrs. work on visual performance test	6	(-)	
Smith, G. M.	1946	Altitude 10,000 ft - 7+ hrs.	16	(-)	
Smith, G. M.	1948	"	16	(-)	
Lee and McPherson	1948	"Tropical fatigue"	1750 military personnel	(-)	Personal and psychological factors of paramount importance.

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In the compilation of the bibliography the appended lists of journals and general sources were searched systematically for studies dealing with the conditions associated with aircraft flight or with other conditions resulting in performance impairment, namely, altitude, noise, vibration, temperature, humidity, sleep privation, fatigue, stress, drugs or dietary modifications. After preliminary survey, articles dealing primarily with the following subjects were largely excluded: physiological, clinical and psychiatric effects; physical fitness; physiological or muscular work output; sensory or perceptual tests; selection, classification and training of service personnel; noise studies in communication; radar and other military performance; subjective observations; changes in personality, general intelligence; and similar studies.

A residuum of articles, in which quantitative estimation of performance was attempted, remained. The bibliographies of these articles gave leads to others in journals not included in the search. In this phase of the work an attempt was made to be as comprehensive as possible in the time available. Because of the limited scope no attempt was made to survey the literature other than in English, with the exception of Industrielle Psychotechnik.

After the compilation of the quantitative tests, which had been used to estimate decrement under deleterious conditions, was completed, a further series of studies was consulted for test descriptions, modifications, evaluation of technique and interpretation of function. The articles of this sort do not constitute an exhaustive list for any given test, nor are they necessarily the best in the field, but are rather the ones which have been most influential in determining the course of experiments in the field of decrement testing.

List of Journals Searched Systematically

	Volumes	Years
American Journal of Physiology (Amer. J. Physiol.)	135-156	1941-1949
American Journal of Psychology (Amer. J. Psychol.)	42-61	1930-1948
American Psychologist (Amer. Psychologist)	1-3	1946-1948
Annual Review of Physiology (Annual Rev. Physiol.)	3-10	1941-1948
Archives of Psychology, N. Y. (Arch. Psychol.)	1-41	1910-1945
British Journal of Industrial Medicine (Brit. J. industr. Med.)	1-4	1944-1947
British Journal of Medical Psychology (Brit. J. med. Psychol.)	15-20	1935-1946
British Journal of Psychology (Brit. J. Psychol.)	1-38	1905-1948
British Journal of Psychology, Monograph Supplement (Brit. J. Psychol. Monogr. Suppl.)	1-9	1911-1939
British Medical Bulletin (Brit. med. Bull.)	2-5	1944-1947
Bulletin of the Canadian Psychological Association (Bull. Canad. psychol. Ass.)	1-6	1940-1946
Canadian Journal of Psychology (Canad. J. Psychol.)	1-2	1947-1948
Comparative Psychology Monographs (Comp. Psychol. Monogr.)	1-19	1922-1948
Journal of Abnormal and Social Psychology (J. abnorm. soc. Psychol.)	35-41	1940-1946
Journal of Applied Physiology (J. appl. Physiol.)	1	1948-1949
Journal of Applied Psychology (J. appl. Psychol.)	24-32	1940-1948
Journal of Aviation Medicine (J. aviat. Med.)	1-19	1930-1948

List of Journals Searched Systematically (con.)

	Volumes	Years
Journal of Comparative Psychology - Journal of Comparative and Physiological Psychology (J. comp. Psychol. - J. comp. physiol. Psychol.)	1-41	1921-1947
Journal of Consulting Psychology (J. consult. Psychol.)	1-10	1937-1946
Journal of Experimental Psychology (J. exp. Psychol.)	1-38	1916-1948
Journal of General Psychology (J. gen. Psychol.)	22-38	1940-1948
Journal of Psychology (J. Psychol.)	9-25	1940-1948
Physiological Review (Physiol. Rev.)	10-26	1930-1946
Proceedings of the Royal Society of London, Series B (Proc. roy. Soc. Ser. B)	106-133	1930-1946
Psychobiology	1-2	1919-1920
Psychological Abstracts (Psychol. Abstr.)	14-22	1940-1948
Psychological Bulletin (Psychol. Bull.)	1-45	1904-1948
Psychological Record (Psychol. Rec.)	1-5	1938-1945
Psychological Review (Psychol. Rev.)	37-55	1930-1948
Quarterly Journal of Experimental Psychology (Quart. J. exp. Psychol.)	1	1948

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